NEW ENGLAND WATER WORKS ASSOCIATION.

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This Association, as a body, is not responsible for the statements or opinions of any of its members.

THE WATER WORKS OF CAMBRIDGE, MASS.

BY L. M. HASTINGS, CITY ENGINEER, CAMBRIDGE.

Read June 1, 1896.

HISTORY.

In order to clearly understand a description of the Cambridge Water Works, a brief glance at its history will be necessary.

The first public water supply was introduced into the city by the "Cambridgeport Aqueduct Company," chartered in 1837, taking water from springs on Prospect Hill, Somerville, and conducting, by means of wooden pipes, the water to the consumers in Cambridge. In 1856 another company was incorporated, called the "Cambridge Water Company," authorized to take water from Fresh Pond, and the surplus water or overflow from Spy and Little ponds, these ponds being situated near the westerly boundary of Cambridge. In 1861 the Cambridge Water Company bought out the original Aqueduct Company, and in turn the entire works were sold, in 1865, to the city of Cambridge for the sum of $291,400. At this time (1865) the population was 29,112. I may add here, that the total amount paid on account of Water Works Construction to December, 1895, has been $4,022,681.92.

Various grants for increasing the supply have been given by the Legislature of this State from time to time, the most important of which was the right granted, in 1884, to take the water of Stony Brook, a tributary of the Charles River, lying in the city of Waltham,

and the towns of Weston, Lincoln, and Lexington. The water from this brook is now the chief reliance of the city, and it is in the development of this supply that the extension of the present system consists, the yield from Fresh Pond now forming a very inconsiderable portion of the Cambridge supply. Cambridge has at present a population of about eighty-four thousand, and had an average daily consumption, in 1895, of 6,000,000 gallons or 71.65 gallons per day per capita.

THE PRESENT SUPPLY AND WORKS.

Water is gathered at the Stony Brook Basin, near its junction with Charles River, — this basin holding about three hundred and fifty million gallons. This dam and basin were constructed in 1887. From here the water is conveyed by a cast-iron pipe conduit, 30 inches in diameter and nearly eight miles long, to Fresh Pond, which stores about four hundred million gallons.

A very curious fact about Fresh Pond is its extremely low elevation. When full, it is but about one foot above the level of mean high tide in Boston Harbor, and it has been pumped so low as to be about on the same elevation as mean low water, or ten feet below high tide level. The mingled waters of Fresh Pond and Stony Brook are now pumped from this low elevation to the present reservoir and standpipe in the city, and so delivered to the consumers through 125.19 miles of water pipes, and 12,681 service connections. A small part of the water is pumped by high service pumps, so as to give a pressure of about sixty pounds per square inch, but the larger portion is pumped to the reservoir, giving about thirty-five pounds per square inch pressure.

The present estimated capacity or available yield of the supply is 7,250,000 gallons daily; 1,250,000 gallons from Fresh Pond, and 6,000,000 gallons from Stony Brook. It will thus be seen that the consumption is close on to the present capacity of the works.

EXTENSION OF THE WATER WORKS.

The large and expensive extensions to the works, now being constructed, are for the purpose of accomplishing three objects: first, increasing the supply; second, increasing the pressure; third, increasing the pumping capacity.

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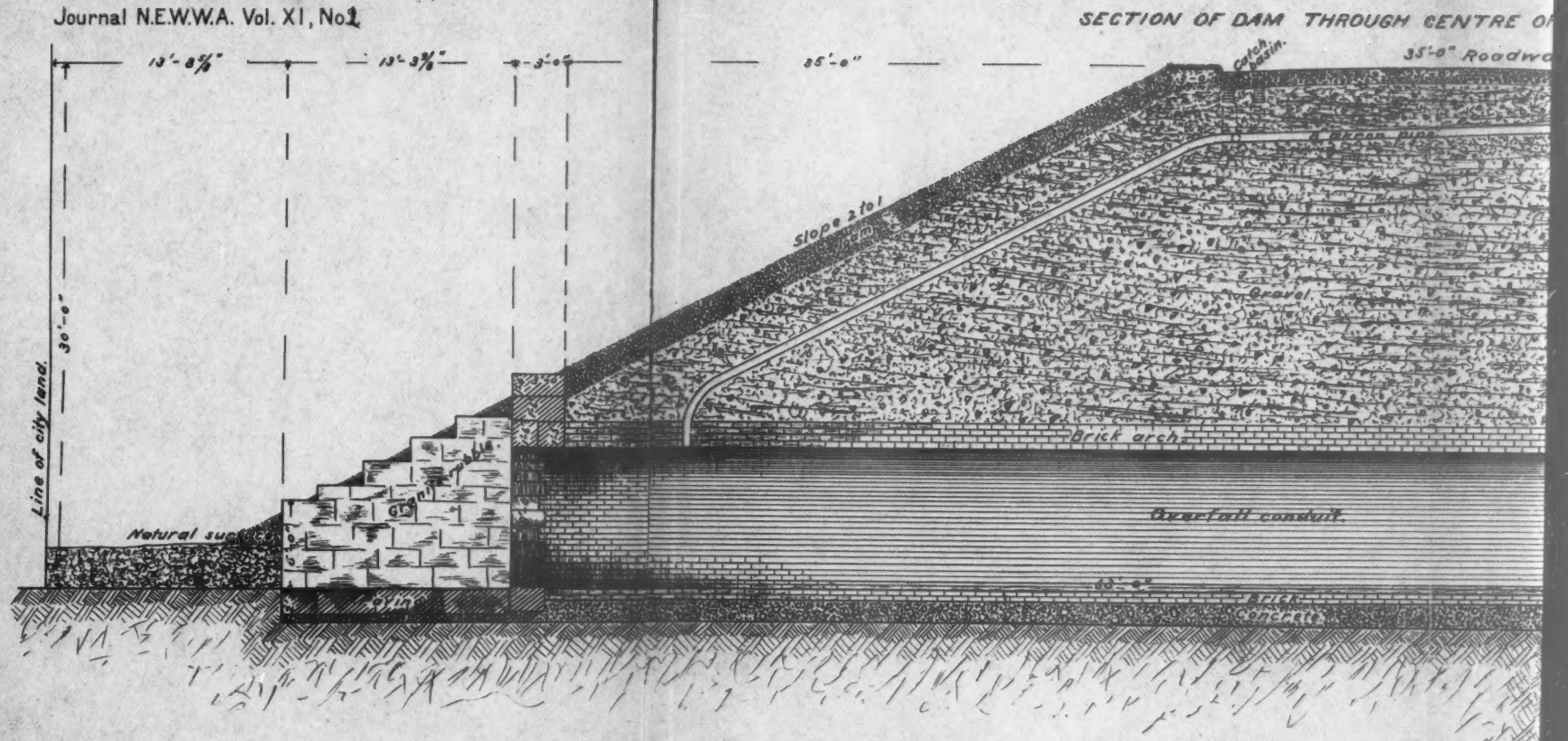


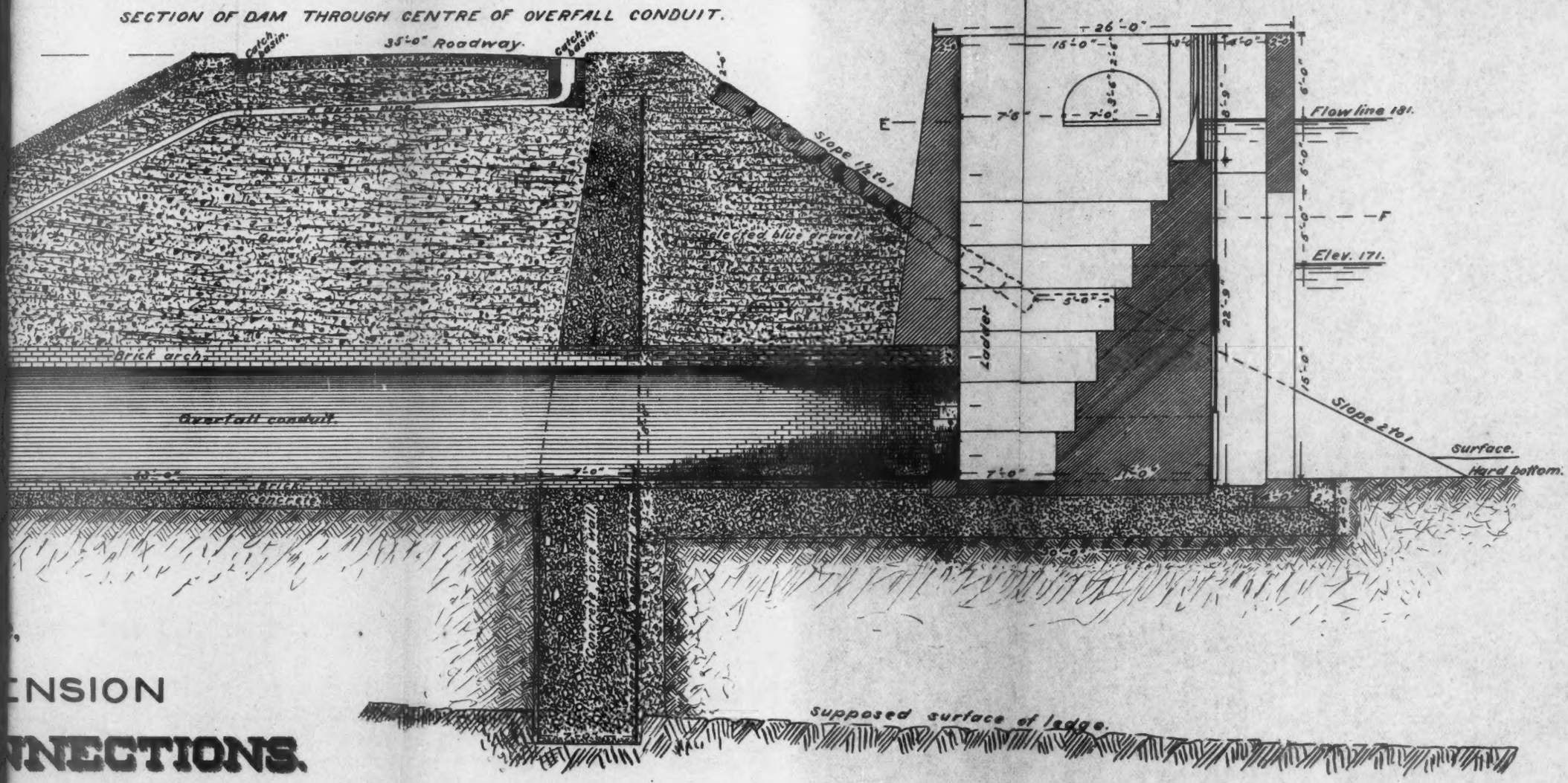
City of Cambridge,

WATER WORKS EXTENSION

WINTER ST. DAM AND CONNECTIONS.

JAN. 14, 1895.

L. M. Hastings
City Engineer.



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NNECTIONS.

Hastings
City Engineer.

Heliotype Printing Co. Boston

HOBBS BROOK STORAGE BASIN.

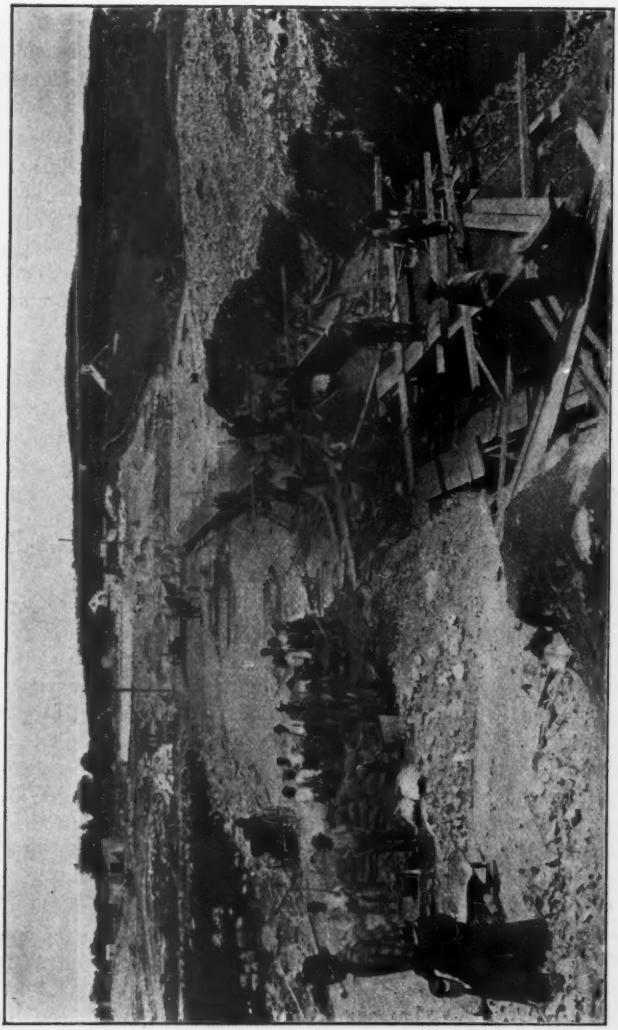
The only way the supply could be increased was by enlarged storage. The area of the watershed of Stony Brook is 22 square miles. This should yield, with adequate storage capacity, about eighteen million gallons daily, instead of the six million gallons now obtainable. To increase the storage capacity on this watershed, about one thousand acres of land have been taken by the Water Board on Hobbs Brook, a branch of Stony Brook, and the work of construction is now well advanced. Two dams are being built: one at a narrow place in the valley, where it is crossed by Lincoln Street, and another, the main dam, at the lower end of the valley near Winter Street, in Waltham. Both dams are built mainly of earth and have concrete core walls; both carry a highway on the top.

The main dam at Winter Street is 35 feet wide on top, with slope of $1\frac{1}{2}$ to 1 foot on the water side, and 2 to 1 on the loam side. The core wall, 7 feet thick, is carried to the bed rock, 16 to 18 feet below the surface; the length of the dam is about one thousand feet.

This dam is pierced by a large overflow conduit or waste way, about 7 feet in diameter, located at the bed of the brook. Flash boards in a chamber built at the end of this conduit regulate the height of the water, and, with a relief waste way or overflow in the crest of the dam at one end, provide an outlet for freshet water. The water in the basin controlled by the dam will be 165 feet above the level of the water in Fresh Pond.

It may be of interest to quote a few prices at which the work of construction at this dam is being done in quite a satisfactory manner. American concrete, of the usual proportions, is being placed, at $3.10 per cubic yard; Portland concrete, $4.75 per cubic yard; plastering of Portland cement, one half inch thick, 27 cents per square yard; excavation and construction of dam, 38 cents per cubic yard; field stone slope paving is being laid at $1.10 per square yard; brick masonry in Portland cement mortar, $10.29 per cubic yard; broken stone furnished and placed, 89 cents per cubic yard.

The dam at Lincoln Street is much the same in design as the one at Winter Street. It has a length of about six hundred feet and a width on top of 27 feet. A few of the prices paid here are as follows: American concrete, $4.00 per cubic yard; plastering, 10 cents per square yard; earth embankment construction, 27 cents per cubic yard; field stone slope paving, $1.00 per cubic yard.



WINTER STREET DAM.

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Journal N.E.W.W.A. Vol. XI, No. 1.

City of Cambridge,

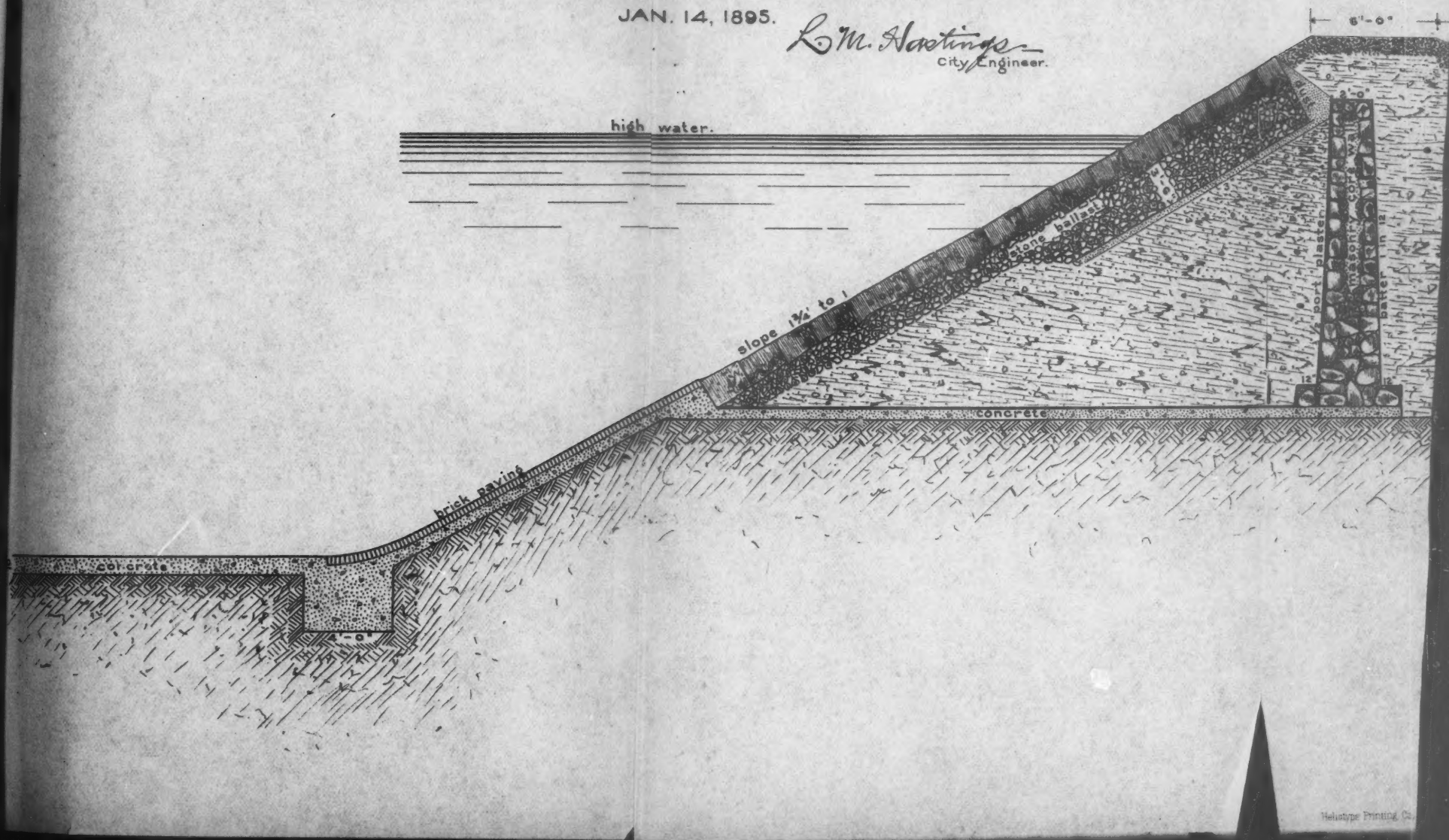
WATER WORKS EXTENSION

WINTER ST. DAM & CONNECTIONS.

TYPICAL SECTI

JAN. 14, 1895.

L. M. Hastings
City Engineer.



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AM AND CONNECTIONS.

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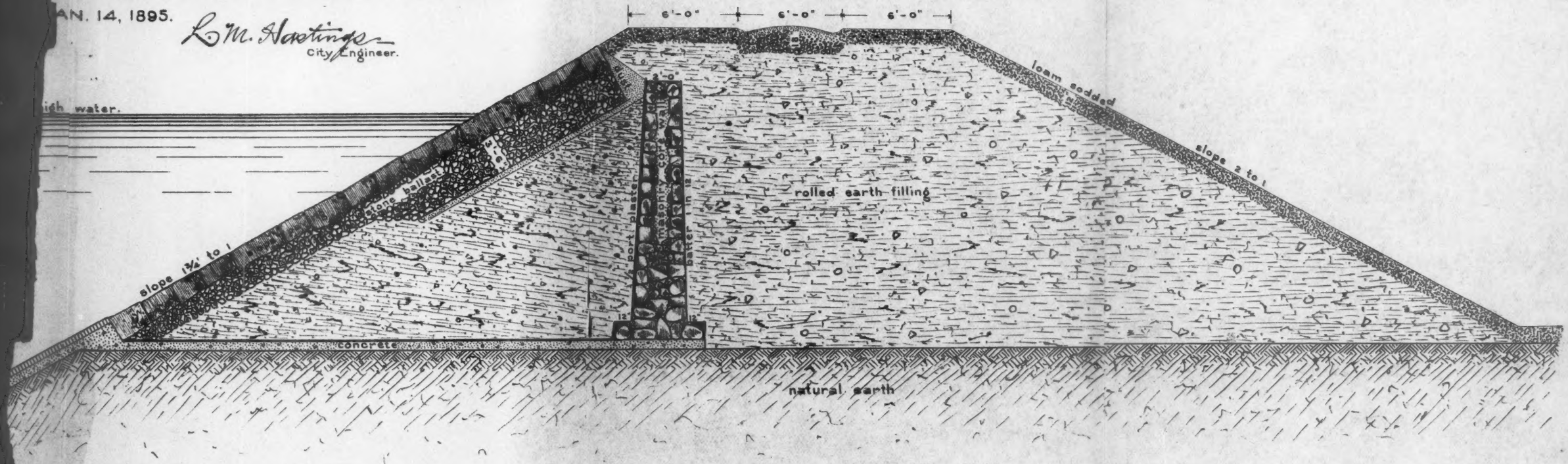
City Engineer.

TYPICAL SECTION OF EMBANKMENT



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The basin, when filled, will be about six hundred and fifty acres in extent and about two and one half miles in length. It will store about 2,000,000,000 gallons and give about 1,500,000,000 gallons available for use. The entire bed of the basin is to be stripped of soil and muck, necessitating the removal of about 1,900,000, cubic yards of material. Prices for the work have ruled very low, ranging from 16 to 25 cents per cubic yard — the major part being done for about twenty cents per cubic yard. The work is being done almost entirely by the old-fashioned, yet effective, machine — a one horse dump cart.

From the storage basin formed by these dams, the water is to be let down the natural bed of the brook to the lower basin at Stony Brook, and thence by the iron pipe conduit to Fresh Pond. It is proposed to eventually construct another pipe of larger dimensions, parallel with this conduit from the Stony Brook Reservoir to Fresh Pond.

PAYSON PARK RESERVOIR.

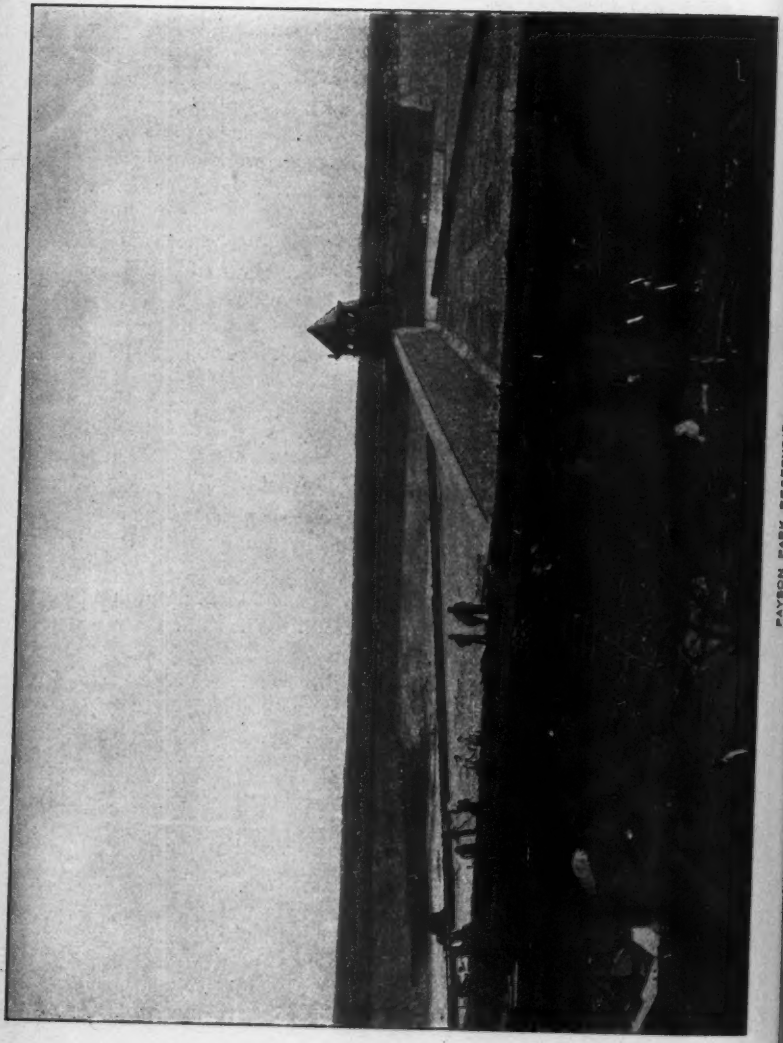
To increase the pressure, a large reservoir is being constructed at Payson Park — this reservoir being connected with the pumping station and the centre of the distributing system by riveted steel pipes, 40 inches in diameter.

This reservoir is 750 feet by 500 feet wide and 20 feet deep, in two compartments, separated by a masonry wall. When full the reservoir will contain 44,000,000 gallons.

The entire reservoir will be lined with concrete. The embankments made from materials excavated from the basin are of the form shown in the plate.

The core wall is formed of field stone, laid solid in cement, and resting on the sheet of concrete at the natural surface. This is all plastered with Portland cement plaster.

The gate chamber will be circular in shape, and will contain the gates and valves controlling the force and supply mains and waste pipes. The water will be delivered by the force mains at the extreme corners of the basins and will be taken out by the supply main through a perforated drum or strainer at the end of a movable section of pipe, which is jointed at one end to a fixed end of the pipe coming from the chamber, the other end of the movable section, to which the strainer is attached, being raised or lowered by means of a float

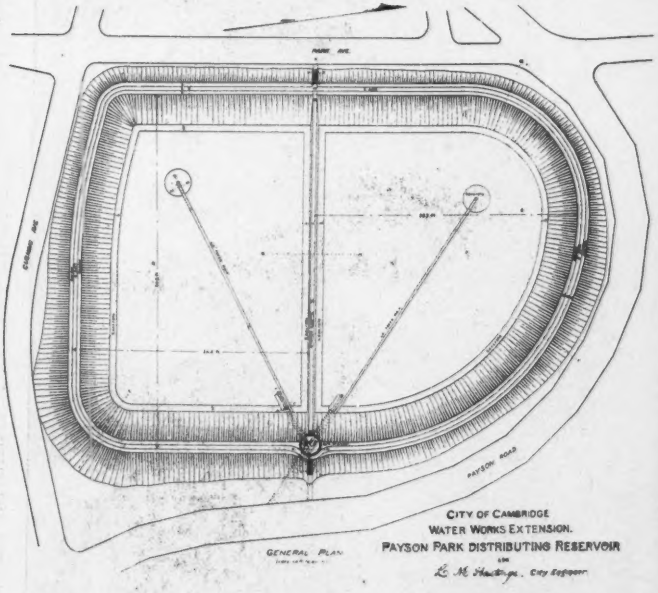


PAYSON PARK RESERVOIR.

GATE CHAMBER AND FITTINGS — PAYSON PARK RESERVOIR.

PAYSON PARK RESERVOIR.

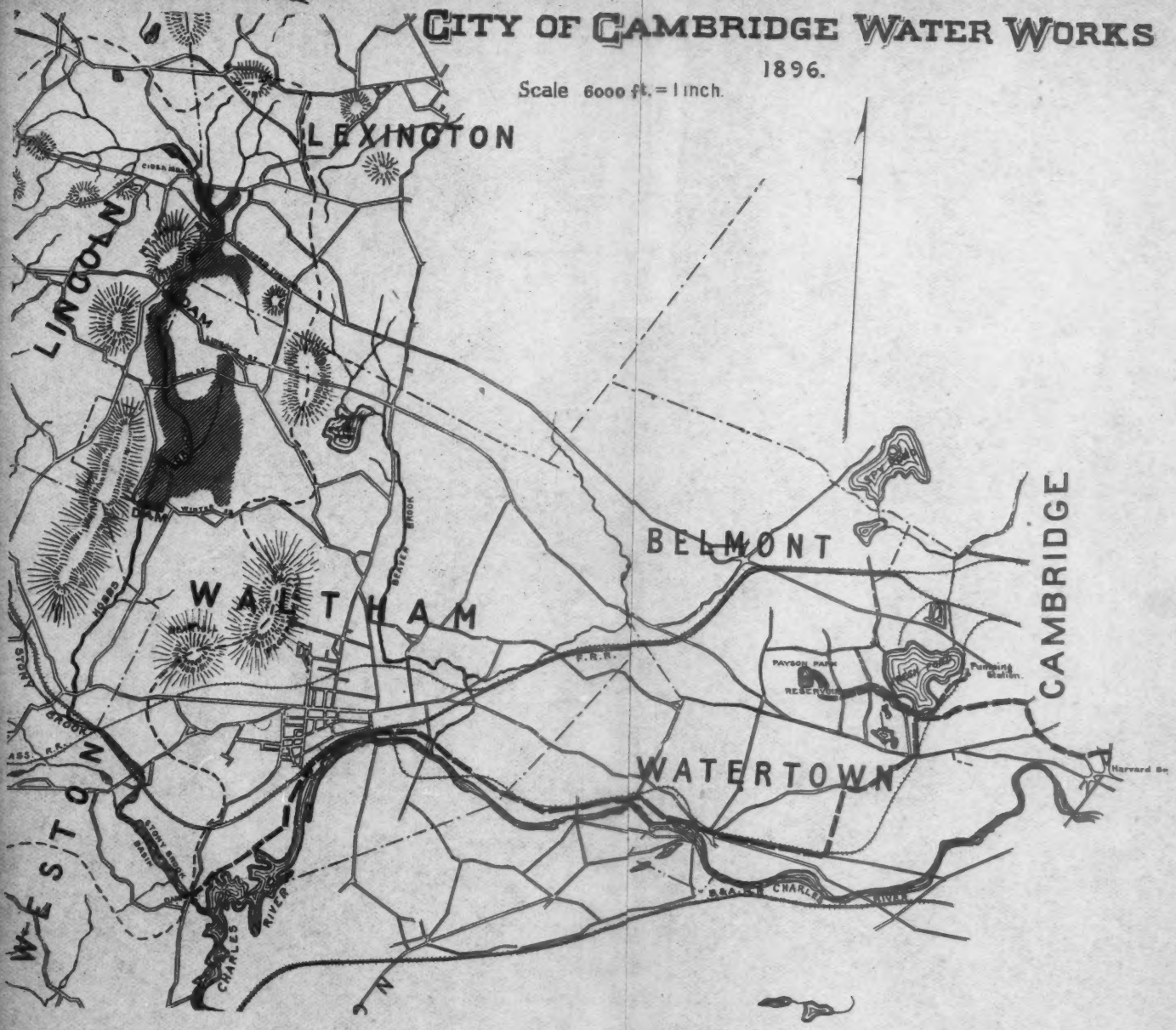
and tackle. The chamber will be surmounted by a gate house, also circular, of brick and stone, from the second or observation story of which, magnificent views of the country can be obtained. The elevation of the water in the reservoir will be 162 feet above the



water in Fresh Pond, or about the same elevation as the water in the new storage basin in Waltham. The whole city will be supplied from this reservoir when it is completed, giving a uniform pressure and only one service.

40″ RIVETED STEEL PIPE.

The riveted steel pipe forming the force and supply mains is made of steel plates $\frac{5}{16}$ of an inch in thickness, and about seven feet long, rolled to circular shape and riveted and caulked like an immensely long boiler. Plates were put together in the inside and outside courses, four plates making one section, about twenty-eight feet long. Each section was then dipped in a protective coating made of linseed oil and asphaltum, and baked in an oven till hard. The



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sections were then delivered on the line, and placed in the trench and the sections riveted together by hand. The trenching and refilling for the pipe was done by the city, and the contractor furnished, placed, and riveted the pipe. Twenty-three sections, or 644 feet of pipe, was the largest amount of pipe placed ready for riveting in any one day. Curves were made by shearing the plates to a mitre and then riveting up. One hundred feet was the smallest radius used. At two points on the line the pipe was carried over deep cuts. At one, for a railroad, and once over a roadway. The plates here were $\frac{3}{8}$ inch thick, and the pipe made self supporting between the abutments. In one case a clear span of 75 feet, and in the other a span of 94 feet was used. In the long span the pipe was re-enforced by riveting on to the top and bottom two heavy 6″ angle irons, extending about two thirds of the length of the span. As these pipes were exposed to large variations of temperature, expansion joints were placed at one end of each exposed pipe, to allow a free movement of the pipe. After the pipe was placed in the trench and riveted up, it was tested in sections of convenient length, to a pressure of 100 pounds per square inch by water pressure, and all leaks stopped. The joints made in the field and all defects in coating were covered with two coats of asphalt paint. The contract price for the pipe, complete and tested in the trench, was $4.57 per lineal foot. The cost of trenching and refilling for the pipe was about $1.75 per foot, making a total cost of about $6.32 per foot. The top of the pipes was placed at an average depth of 4 feet below the surface of the ground.

The total length of 40″ pipe laid or to be laid, including fittings and cast-iron pipe, is 24,500 feet. Eighty-four hundred feet of the line was laid with two pipes (the force and supply mains) in one trench, and about eighteen inches apart.

While the pipe was being laid, a curious accident happened, which illustrates the flexibility of even a pipe with as large a diameter as 40″. A stretch of pipe had been riveted up and awaited testing; the trench being in low ground, and not refilled, Oct. 13 and 14, a very heavy rain came and filled the low portion of the trench, and about four hundred and twenty-five feet of the pipe floated up, having less specific gravity empty than water, rising about three feet in places. The trench was dried out and the pipe forced back in place by loading on top, with but little damage to pipe or riveting.

The valves used in the line are 36 inches in diameter, and are made very strong and heavy, by the Coffin Valve Co. It was not thought

40" STEEL PIPE—PAYSON PARK RESERVOIR.

CURVE IN 40" STEEL PIPE — PAYSON PARK RESERVOIR.

that the reduction from 40″ to 36″ in diameter would impair the efficiency of the pipe.

The question of movements of the pipe due to temperature was carefully considered, and a simple form of stuffing-box expansion joint was introduced at the ends of the exposed portion of the pipes, as referred to above, where dangerous strains were liable to occur, and at the connections with the valves.

These joints were made in two sections of cast-iron, one section, having a spigot end, had on the inside a brass bushing attached. The other section had a long, deep hub, into which the first or spigot section fitted. The joint between the two sections was made up of lead and caulked; fifteen of these joints were used on this line. Air valves were placed at the summits and blow-offs at the low points.

NEW PUMP.

The pumping capacity is to be increased by the addition of a new high duty pump, of a capacity of 20,000,000 gallons per day, designed by E. D. Leavitt and now being built by the Groshon High Duty Pumping Engine Company of New York.

This engine will be 53 feet 3 inches in height, with fly wheel 25 feet in diameter, pumping 229 gallons of water for each stroke. There will be about five hundred tons of metal used in its construction. The engine is to possess the high qualities for which Mr. Leavitt's work is noted, with all the modern improvements.

The work above described is expected to cost from $1,250,000 to $1,500,000, and the supply is estimated to be sufficient to last the city of Cambridge for about twenty-five years, or until about 1920.

DISCUSSION.

Mr. Stearns. I would like to ask Mr. Hastings if any part of the system is in use now, either the reservoirs or pipes?

Mr. Hastings. Yes; part of the 40-inch pipe has been in use since last winter, but the reservoir is not completed, nor the storage basin.

Mr. Fuller. I would like to ask Mr. Hastings if all this water is to be pumped. I understood that the distributing reservoir at Payson Park is about the same level as the reservoir at Waltham; can any of the water be carried into the distributing reservoir without being pumped?

Mr. HASTINGS. No, sir. That matter was carefully considered, and it was found to be impracticable to lead it down from the storage basin, which is almost at the same elevation as the Payson Park reservoir. All the water will run down hill and then be pumped up to the reservoir back at practically the height it starts from.

The PRESIDENT. Are there any intervening hills which prevented you from adopting another plan?

Mr. HASTINGS. It was quite a complicated question, and it was also a question whether we should use the Stony Brook basin as a distributing reservoir or build another one. I could not begin to explain all the points, but it was decided after careful consideration that on the whole the best plan would be to use that simply as a storage basin and the other as a distributing reservoir. It seems absurd and unmechanical to let water run down hill and then pump it up again, but that is exactly what we are going to do.

Mr. STEARNS. It is true, is it not, Mr. Hastings, that only a comparatively small part of the water will come from this new reservoir, so even if you provided for bringing that in it wouldn't aid you with regard to the rest?

Mr. HASTINGS. The question was, why should we build the Payson Park reservoir when we were to have another much larger one at the same height.

Mr. STEARNS. I thought the idea was to get it without pumping at all.

Mr. HASTINGS. We couldn't do that. That was one of the questions involved. Part of the year we might draw it direct by gravity from this upper reservoir; the rest of the year we would have to pump against that head.

The PRESIDENT. Will you describe the waste way to that upper reservoir a little more fully? What is the capacity there represented in inches of rainfall, do you remember?

Mr. HASTINGS. I think 6 inches in 24 hours is estimated.

Mr. PRESIDENT. That is carried through those ports?

Mr. HASTINGS. Yes; there are five ports in the chamber, and what I call the relief waste way to serve in case of choking or any possible obstruction is 15 feet wide besides that.

The PRESIDENT. Is that in another part?

Mr. HASTINGS. Yes; in another part entirely independent of this chamber.

The PRESIDENT. That is a waste way?

Mr. HASTINGS. Yes, sir; for that purpose and nothing else.

The PRESIDENT. Can you tell us a little more fully about the coating of that pipe? Does it peal off, or is it hard?

Mr. HASTINGS. It seems to be quite hard. There was one place left open through the winter, and this spring, where it was bedded in clay, a few patches of it did come off. The frost seemed to have some effect on it, and some patches came off like a film.

The PRESIDENT. It didn't scale off in great flakes?

Mr. HASTINGS. No, sir; it was very firm and adhesive, that is in handling and getting it in place.

The PRESIDENT. What do you lay that to, a superior method employed?

Mr. HASTINGS. It is a kind of japan. It is dipped while the metal is hot, and the pores are supposed to be open, it is dipped in hot asphalt, which is then baked on like a japan. It really is a japan.

The PRESIDENT. Wasn't that same process used in treating some of the other steel lines?

Mr. HASTINGS. Yes, sir; Rochester and Allegheny.

The PRESIDENT. Didn't it come off of the Rochester pipe in great flakes?

Mr. HASTINGS. They used two processes. Half of their pipe line was dipped in common asphalt melted in a tank, and the pipe dipped in cold, what is called a maltha bath The other part was dipped in the combination I spoke of, a combination of asphalt and linseed oil, which is baked or fired right on to the metal.

The PRESIDENT. That seems to you to be satisfactory?

Mr. HASTINGS. It has worked very well so far; of course only time will prove its durability.

The PRESIDENT. How were the seams brought together, and what calculations were made as to the carrying capacity of the pipe?

Mr. HASTINGS. We didn't have to do a close figuring. The Water Board wanted it big enough, so I figured on an ample basis, and no fine estimates were made of the obstruction that these rings or rivet heads would cause. As long as I got it big enough, and a little more it was satisfactory.

The PRESIDENT. Were the embankments rolled in thin layers?

Mr. HASTINGS. Yes, sir; 4-inch layers and 6-inch on the outside.

Mr. SMITH. You spoke of some portions where you had laid two lines of pipe. Was the pipe of different diameter, or why were the pipes laid in that way?

Mr. HASTINGS. The idea was that in running from the Fresh Pond station to the reservoir and then back into the city the two lines came together part of the way and then they diverged, one going to the pumping station and one to the city.

Mr. SMITH. It was all the same size pipe?

Mr. HASTINGS. Yes, exactly the same.

Mr. SMITH. But the water flowing in different directions?

Mr. HASTINGS. Yes, sir.

Mr. STEARNS. Is there a connection between those pipes so one can be used independently of the other?

Mr. HASTINGS. Yes; there are three gates and cross-over connections so that one can be used and switched off and the other one used alternately.

Mr. STEARNS. So by having the two pipes you have a reserve, and ordinarily you intend to pump to the reservoir through one and draw through the other, or will you have them both open?

Mr. HASTINGS. They would both be open and we can pump through one and draw through the other, or they can be switched off so we can use either one as a force main or as a supply main.

Mr. STEARNS. I don't know as I quite understand. Is it the intention to open both pipes so the water will go freely, or is all the water to be forced up to the reservoir through one pipe and to come back through the other pipe?

Mr. HASTINGS. Well, ordinarily we would pump right into the reservoir and draw it right back again.

Mr. STEARNS. Is that with the view of improving the quality of the water?

Mr. HASTINGS. Yes; the idea is to keep a constant circulation of water in the reservoir. If we didn't do that we should have stagnant water in the reservoir. We could pump into the circulation and simply have that pressure to pump against, but that would make stagnant water there, so it was thought best to pump into the reservoir and then draw it out.

Mr. STEARNS. So it is for the purpose of maintaining the good quality of the water?

Mr. HASTINGS. Yes, sir; that is the idea.

Mr. FULLER. Couldn't you have an arrangement of check-valves so you could discharge the water at the further end and take it from the nearer corner of the reservoir?

Mr. HASTINGS. Not if we only use one pipe for the force and

supply main. If we pumped 6,000,000 gallons a day we would have the reservoir full and the water would simply go right around, and not into the reservoir at all, and the water in the reservoir would stay there as a pressure. That was one reason why we had two lines. The water will have now to go to the reservoir and come out, while if we had only one line and used that as a force and supply main, the water would stay in the reservoir and become stagnant.

Mr. FULLER. Couldn't you have a check-valve so the water would be discharged at that end and only come back at this end?

Mr. HASTINGS. But ordinarily you would be only pumping your consumption, which would mean you would pump into the city direct, and there would be no water going into the reservoir at all. It might lie there three months and never change. By having the two lines there has got to be a circulation.

Mr. FULLER. You mean the water which was pumped would be used, and the water in the reservoir would remain there?

Mr. HASTINGS. That is just it.

Mr. SMITH. Can you give us any explanation of how you were able to get such low prices on your work?

Mr. HASTINGS. No; I don't know as I can. We had quite a large number of bidders, and we seemed to strike a low period in the market. The contractors are doing very satisfactory work for the most part.

HOW TO SECURE PURE WATER FROM A SURFACE WATER SUPPLY.

BY JOHN C. HASKELL, SUPT., LYNN, MASS.

[*Read June* 10, 1896.]

In considering a subject that has been such an essential factor in the very existence of mankind since their creation, it would seem that little would remain to be said, and that all of the steps to be taken in the practical development of a system of surface water supply for our cities and towns had been in the past so fully developed and thoroughly tested by their subsequent use that we would have no differences in opinion. As to the methods to be followed to maintain at all times in our distributing reservoirs water of a good, wholesome character, with no disagreeable taste or odor, destitute of color and not dangerous to health, all will agree that water to be used to quench our thirst should possess these qualities.

I will, at this time, state that we have in the basement of the City Hall a laboratory in which biological examinations are made weekly, of samples of water taken at points one foot below the surface and one foot above the bed of all our ponds. During the meeting of this Association drawings showing all of the different organisms that have at any time been discovered in our water supply, also an opportunity to examine such organisms as are at present to be found in any of our ponds, together with an explanation of the details necessary to a thorough study of the character of the water, will be open to the members of the New England Water Works Association. All interested are invited to visit the laboratory on any day between the hours of 8 A. M. and 5 P. M.

Although this is a subject of great importance, and one which covers a wide field for special study in different directions, upon each of which much information is occasionally presented by specialists who are giving their undivided attention in one direction, it is one which has not been given the prominence it deserves, and as yet is imperfectly understood. In order to bring this subject before you,

I will endeavor to present some of the details brought to my observation since the inception of our system of water works, together with the effects that I consider them likely to produce upon a surface water supply.

It is known to all engaged in the management of surface water supplies that the quality of water furnished by them for daily consumption is not always of the best character, and that it is liable to differ in quality from time to time.

Such changes should be avoided, if possible, and the standard of purity maintained at all times up to the best permissible in that system of water supply. To accomplish such a result it is necessary to know what produces the various changes so noticeable, and of the best methods to be followed for their prevention.

One of the principal reasons why our knowledge in this direction is so insufficient is the additional expense to be incurred in the construction and maintenance of a system, with special attention given to securing its purity.

The usual course pursued by expert engineers until within a few years, in providing a system of water supply by artificially storing water in a reservoir formed by constructing a dam across the valley of a small stream or river, gave very little thought as to the liability of a change in the character of the water impounded therein.

Water was what was wanted, and the solution reached forward to was quantity, not quality.

From the first use of water from these artificial reservoirs it was found that at times it possessed very disagreeable qualities.

While the causes in the frequent changes in the character of water impounded in reservoirs was not at first understood, the careful and constant examinations of their waters, both chemically and microscopically, has furnished us with sufficient information to show us what produces these changes, and from what particular organisms or different combination of organisms we are deriving these undesired qualities in our water.

Some of the organisms existing in large numbers at times in our waters are not injurious in any way to the character of the water except to sight. Others, although invisible to sight, are disagreeable, both in taste and odor; some possess all of the disagreeable attributes. While it is generally claimed that the presence of large amounts of decaying vegetable organisms in our waters is not dangerous to

health, it is certainly very disagreeable, and in my opinion not altogether harmless.

There is now no mystery as to what produces the poor water in our reservoirs. The cause in any case can be ascertained. The proper solution of the best and most practical methods of eliminating all injurious organisms from our waters is the feature to be desired. As far as possible all dangerous contributing constituents should be excluded. Rain falling upon a water-shed is comparatively pure.

To gather this water falling upon a water-shed, impound it in a reservoir and deliver it at the tap in the city in a pure condition at the least expense, is a problem that is far from being solved. From the first contact of the rain with the earth on the water-shed its liability to contamination begins.

Upon a hilly wooded country containing no artificial pollution, comparatively no danger exists. An examination of the water found in the brooks at the base of such areas shows water of the best character. Upon reaching low, swampy areas, where the flow of water is impeded from the level nature of the ground, giving it time to settle into the soil and stand among the roots of shrubs and trees until it has absorbed some of their taste and odor, is one of the first sources of contamination.

This danger should be eliminated as far as possible by separating the swampy portion of the water-shed from the hilly, by ditches at the edge of the swamps sufficient in size to carry the water from the upland around the swamps. Where the depth of soil will admit, the water-table of the swamp should be lowered by means of ditches to the gravel or sand below the soil, thus requiring the water to simply pass downward a few feet through the soil to the gravel below, instead of a long distance through the surface of the swamp.

A partial result in this direction is shown as resulting from work upon the water-shed of Walden Pond in 1895, which reduced the color of the water in the pond, as shown by the weekly examinations, from 76 in 1895 to 43 for the corresponding time in 1896. This reduction in color is perceptible and can be expressed in figures; undoubtedly the diminution in taste and odor, which cannot be shown so clearly, was greater.

After providing the best channels to convey the water from the entire water-shed, we come to the artificial reservoir. Until quite recently expert engineers made no attempt to remove the soil and

perishable material from the bed of new reservoirs, claiming that the expense should not be incurred, as the beds of the reservoirs when covered with water would improve from year to year. Until within a short period, less than ten years, they would become equally as good as the old ponds which were formed by nature. This reasoning, however, has been in many cases proven to be erroneous, as no perceptible improvement has been found to take place in some of these reservoirs in a longer period, and in all probability these ponds will never furnish a good bed from natural causes.

It is also known that natural ponds are not entirely exempt from these periodical changes in the character of the water, some being much less liable than others, but no absolute certainty exists that their water will be pure at all times.

Our experience is based upon artificial reservoirs.

The two first, Breeds and Birch ponds, were purified to a large extent by natural causes, but still each year at times furnish growths of organisms that render the water disagreeable. The improvement in the other ponds, Walden and Glen Lewis, has not been so rapid. In Glen Lewis no perceptible improvement has been seen. Its value as a storage reservoir, however, is not destroyed, from the fact that the water is of good character a sufficient portion of the time to allow its use without any waste.

In Walden Pond some work has been done to improve the character of the water. This work became necessary from the fact that the total capacity of Breeds and Birch ponds, from which we have been obliged to draw water during the summer months, would be insufficient to supply the probable consumption for the summer of 1895; and it was necessary to delay, if possible, the growths of organisms in Walden Pond sufficiently late into the summer to meet the expected deficiency with an ample supply of good, potable water.

In our endeavor to accomplish this result, and with a view to ascertain as nearly as possible whether the results to be obtained by removing all soil from the bed of the pond might not be equally well subserved by a covering of sand or gravel over the soil to a sufficient depth to effectually destroy its pernicious effect on the water, a portion of this area, containing mud from fifteen to thirty-five feet in depth, was selected as an area upon which the expense of removal would be practically prohibitive, and also where the chances of failure to secure good results were most likely to be found.

The surface of this area was mud, with water standing near and upon a portion of its area, it being of such a nature that gravel would readily sink to an unknown depth. All stumps within this area were allowed to remain. Other stumps were removed from the adjacent area, from which all soil was to be removed and placed over the muddy area to form a more stable bed than the wet soil, finally covering all with about one foot of gravel. The bed of the pond was burned over and was exposed to the alternate freezing and thawing through the winter. The success attendant upon this effort is shown from the fact that the water became unfit for use on May 25, 1893, and on May 23, 1894; but in 1895 the water remained a good, potable water, remarkably free from algæ growth until July 10, a sufficiently late date to furnish the needed supply, when it was again wasted to permit further work in this direction. An examination of the different exposed areas showed an equally good appearance of the covered areas and those from which all soil was removed.

Immediately after the bed of the pond was exposed to view, samples of the gravel from the areas cleared, and soil from the areas not disturbed, were taken, to determine as far as possible what advantage was gained by our labor.

These samples, in equal numbers from the sand and soil, were collected at points not more than two feet distant from each other and placed in a dish of water to develop all animal and vegetable life that could be germinated. In the specimens taken from soil, most of the species of organisms previously found in the waters of the pond were well enough preserved to commence an active growth. The samples of gravel contained practically nothing, although gathered in such close proximity to the others. While there is no question but that the removal of all soil and perishable matter from the bed of the reservoir is a step in the direction of securing the purest water, work of this character has not been completed for a sufficient time to fully prove its effiiciency. I will, however, present some or the features incident to its practical development that occur to me.

The objections to organic matter in the pond are, first, that it supplies the food necessary to sustain the growth of plant life beneath the water as abundantly as it provided for the growth of grass or trees before its submersion.

Secondly, it also provides a resting place, and protection for the

existence of the seeds and spores of plant and animal life, as is so plainly seen from the comparisons of the samples of gravel and soil taken from the bed of Walden Pond in 1894. It will also prove a potent factor in increasing the color, taste, and smell.

The counteracting agencies that are to be feared are that the same causes that furnished the deposits of soil removed will still continue their work. The washing of the hillsides into the valleys will always continue, and from year to year the inflowing waters will carry organic matter that will be deposited by sedimentation upon the bed of the reservoir, possibly in sufficient quantities to supply in a short period of time all of the food necessary to support the vegetable and animal organisms, and thus neutralize to some extent the good results produced by the process of cleaning the bed of the pond. Again it may be found that the water flowing in the bed of the streams, at times contains sufficient food to sustain the objectionable organisms. That this may be probable is shown from our experience in our distributing reservoir in April, 1894.

This reservoir, although small in area, its water surface being about five acres, with a capacity of 21,000,000 gallons, in all other respects was of a good character to preserve the purity of the water, the sides being in the nature of an embankment sloping at the rate of two feet horizontal to one foot vertical, with paved slopes and a puddled bottom, the depth of the water, from day to day, from thirteen to fifteen feet. Water was taken from Hawkes Brook and pumped direct into the reservoir. Notwithstanding these favorable conditions, we had in April, 1894, a growth of organisms in the reservoir in sufficient numbers to prove somewhat disagreeable.

Without doubt the food necessary to sustain their growth was brought with the water. We shall in the immediate future have an opportunity to test the new feature, as the entire bed of Hawkes Brook Pond, now in the process of construction, will be thoroughly cleaned.

The next step is to still farther improve the quality of the water by filtration. Although the necessity of filtering water supplies becomes more important according to the density of the population, and in Europe and in tropical countries great numbers of people died from the fearful effects of pestilence engendered and distributed through the medium of their water supplies, the true cause of these diseases was not understood and it remained to scientists of quite

recent date to explain the dreaded mystery which has been the cause of such terrible loss of human life.

The first attempts to improve water by filtration are very ancient and crude in operation, and it is not until a quite recent date that intelligent study has been given in this direction. The comprehensive and careful studies instituted by the State Board of Health and prosecuted in their laboratory at Lawrence, without doubt present the most valuable information to be found upon this study. A careful examination of the tables giving the results secured by their different arrangement of filter beds, presents information of the greatest importance. A large number of experimental filters, embodying various forms of construction, have been in continuous operation under conditions easily conformed to in the practical operation of a system of water supply, a sufficient length of time to have furnished the desired data to show which are the best forms of construction to be used, and also the proper detailed work necessary for their maintenance in proper condition to perform effective work at all times.

It has been found by their examinations that several forms of construction will remove ninety-nine and a fraction of one per cent of all of the bacteria present in the water, a result that is greatly to be desired in our search for the purest water. There are also various mechanical filters capable of doing very effective work.

The location of a system of general filtration should be at the nearest point practicable to the point of distribution.

Additional filtration can be secured at the faucet; many forms of filters have been used, from a cloth tied over the faucet, which acted as a strainer, to the very best mechanical filter yet designed.

Each individual has, through this agency, an opportunity, if so desired, to secure water of the best character.

I know of parties who filter and boil water used for drinking purposes, keeping a supply of water so treated in store in their refrigerators.

Water so treated should be perfectly wholesome in character.

The most thorough methods of filtration have not succeeded as yet in removing all of the odor present in surface waters.

This feature can be largely eliminated by aeration.

This method of improving the quality of our water has not as yet received much attention, but does not present a very difficult problem for solution.

Undoubtedly the time is not far distant when no surface water supply will be considered satisfactory that is not properly filtered.

The importance of filtration has already been recognized in the German Empire by a law obliging its use in all surface water supplies.

DISCUSSION.

Mr. CLEAVER. We have all been deeply interested in listening to this paper, which so clearly presents the experimental and philosophical sides of this question. We are all of us more or less familiar with the various methods of filtration thus far developed, but there is one point in this paper that especially attracted my attention, and I would like to ask Mr. Haskell what he refers to when he speaks of the natural forces which go to the purification and the rendering potable of a surface water, and whether those natural forces are sufficient to solve the problem.

Mr. HASKELL. That question, Mr. President, opens up a sufficiently broad field for treatment in an entire paper. Of course the natural causes referred to are the elements. The sun has an important relation to natural causes. The water which is stored in the pond is a most potent natural cause. Frost is a very important factor in the action upon the surface of the bed of a reservoir; and heat also performs an important function. To illustrate the effect of natural causes upon a pond after it is put in use, we will consider a pond recently constructed, into which the water is allowed to flow until it covers the entire bed of the pond at the height of the overflow. Most ponds have a steep rise at the outer edges to the sides, which are sometimes wooded and sometimes ordinary tillage land. It is on these slopes that the good effect of the action that the water produces upon the soil is first to be found; and to a certain extent on all the hilly portions of the bed of the pond it does the same thing we do where we undertake to clean the pond out by excavating the soil. The first thing noticed is the washing of the water on the soil, when the wind blows it, which loosens the soil at the extreme point where the water touches it, and the soil gradually descends down towards the bed of the pond below. As ponds usually are handled, the water in the pond is gradually drawn lower and lower until perhaps the water level is reduced below the precipitous part of the bed of the pond. A certain amount of soil is washed down in

the first year. In the winter the frost disintegrates and loosens areas that might not have been permeable before the water gets in, and the frost swells and breaks up the particles of the soil, and under the influence of the wind the water washes them down, so that in the course of a short series of years you get as perfect work around all of the outside slopes of the pond as can be performed artificially. The only difference is that the mud is washed down into the deeper part of the pond instead of having been carried away entirely outside the limits of the pond, as it would have been if the work had been done artificially.

Now, the amount of work performed by nature largely depends upon the contour of the reservoir. In a very shallow pond, of course, it only extends to a point slightly below the surface of the water when the pond is full. If the pond were of sufficient depth, and these processes were continued long enough, I have no doubt that the soil would ultimately be removed to a point sufficiently low beneath the surface of the water so there would be no opportunity for the organisms to develop in the soil. There is a point, — I wish I could tell you how deep it is, — that if the water was kept above, there would be no danger to be apprehended from mud in the pond; but I do not know that that point has ever been determined yet. These natural causes work in all reservoirs, and in some they have proved sufficient to bring the bed of the pond into very good condition; but in some, particularly where the water is not deep, they have not proved to be of very much value.

Mr. HOLDEN. I notice Mr. Haskell said he drew the water off to let the frost work on the pond during the winter, and didn't fill it until spring. Is that any better than it would have been to have filled it in the fall, if that could have been done, and then to have drawn it off in the spring and allowed it to refill?

Mr. HASKELL. In our case we let the water out, because we had poor water, and the pond would refill with water of better quality. And there was another reason for letting it off. There were large numbers of organisms in the water, and also their seeds and spores that will multiply in great numbers; and we expected that during the winter the frost would kill, to a great extent, these seeds and spores. Then again, we know that these are near the surface, some of them are on the top, and so we burned it over, hoping by means of fire to destroy all we could. Then the shorter the length

of time the water remained in the reservoir, the less opportunity would be given for the germination of these seeds and their growth. We let the water off through the winter and did n't undertake to store it until the spring rains started an abundant flow of water. The melting snows and the natural rainfall was sufficiently great so we were not obliged to commence to store our water until the latter part of the winter, nearly in the spring, in order to gather all the water we desired. We didn't entirely fill the pond but we got an abundance of water, and the good quality of that we did get was more important to us than it would have been to have a large amount of poor water.

Mr. NOYES. I would like to ask Mr. Haskell if, by that method of drawing the water off and allowing the bed to freeze and the frost to act upon it, the quality of the water obtained from that reservoir has been permanently improved.

Mr. HASKELL. A sufficiently long time has not yet elapsed to enable me to answer that question definitely. It undoubtedly helped us through the trouble that we were in at the time. But I should be doubtful whether in a bed constituted as ours is it would be of much permanent value, because the greater portion of the bed is level. I doubt if it would ever permanently improve from natural causes. I am satisfied that with the conditions to be met with in that pond, there never would be a proper bed made through the action of natural causes, but it will have to be cleaned thoroughly.

The PRESIDENT. Did I understand you to say that the action of the water on the sides of the pond, where the shallow places were not stripped off or protected, would in time improve the sides of the pond?

Mr. HASKELL. On the sides of our pond there were points where it was 2 feet, and some points where there were not over 6 inches of soil, and to have renovated that thoroughly artificially would have required at some points an excavation 8 inches in depth, and at other points 2 feet or 2½ feet in depth. Supposing, for instance, the full pond is 17 feet, as the water lowers down to 16 feet a sufficiently heavy wind to make a sea a foot high would have a washing action on the precipitous bank, and each time the water runs up a foot on the bank any portion of the soil which has disintegrated enough to wash down will be brought down; and then as the water goes down from the 16-foot level to 15 feet the same process will be repeated, and so on. And each year, in the winter, certain portions of this soil, that perhaps are too hard, or of too

solid a nature for the water to bring down, will be broken up and disintegrated by the frost. Supposing there came a rain and the soil filled with water, and then it froze right off that night, it would break up that soil so that the water washing on it the next day would bring it down, when perhaps the year before it was not able to do so. And in a certain period constant work of this kind would remove the whole of the soil.

The PRESIDENT. How many years would that take?

Mr. HASKELL. In Birch Pond there is a pretty good opportunity to see. In seven or eight years the upper part of it, was entirely washed out; I think, in fact, in six years. The reason I cannot tell you exactly about it is this, that I was not taking notice of it, and after the pond had been constructed for a certain length of time we raised it, so of course that made a new starting point. The pond has not been in existence for more than thirteen years, and the whole of the soil on the steep slopes has been washed down; it is all good gravel now, just as good as if we had artificially dug it out and teamed it away all around the edge of the pond. I could not say how many years it has been so, but I should say for five or six years certainly there has been practically no soil whatever on the upper portion of it.

Mr. NOYES. The question asked by Mr. Cleaver and answered by Mr. Haskell opens up a very interesting question in regard to the possibility of improving the quality of water which may be stored in ponds or artificial reservoirs by the drawing off of the water from the reservoir and exposing the bottom and sides to the action of the frost in winter. I believe some years ago a similar trouble to that which Mr. Haskell speaks of occurred in another large reservoir in this State, and that that experiment was tried, and the engineer who advised it was sanguine it would improve the quality of the water very materially. We have with us to-day Mr. Goodnough, one of our members, and chief engineer of the State Board of Health. If I remember rightly he has been studying, and has had some recent opportunities of observing the effect of this method of treatment; and I would, with your permission, Mr. President, ask him to state to the Association what the result of those observations were.

Mr. GOODNOUGH. The reservoir to which Mr. Noyes refers was drawn off, I think, in the spring of 1892, and it was filled again in 1893. During 1894 the water was excellent, and during 1895 up to

the latter part of the year, about September. Since then I believe it has been worse than ever. I understood Mr. Haskell to say that experience had not been had for a very long time as to the results of cleaning reservoirs. I may say that there are some reservoirs in the State which have been cleaned for some ten years, and experience with those has been very satisfactory.

Mr. HASKELL. I should like to know if you refer to Basin No. 4 in Boston?

Mr. GOODNOUGH. I do; yes.

Mr. HASKELL. That seems to me the most notable reservoir of that kind of construction, and of course there is no question but what it did excellent work. There are always in all reservoirs contributing elements which render the success in the case of some better than in others. I have carefully examined all of the analyses that have been given by the State Board of Health of the waters in Basin No. 4 since that work was done, also in Basin No. 3 and Basin No. 2. The analyses would go to show that the results derived are the best in Basin No. 4.

It is well known to any one who is studying the growth of organisms that where analyses are taken but once a month, you know very little about what may occur in the pond. Organisms may arise, come to maturity and disappear between the times of examination, — perhaps not absolutely, but to a great extent. And consequently I cannot talk on what may have been found in basins 4, 3 or 2, with the knowledge that I would like to have. President Fitz-Gerald has made an exhaustive study of those reservoirs; he has made examinations with sufficient frequency to thoroughly understand the matter. I refrained from referring to those ponds in my paper from the fact that I did n't know enough about them to speak with confidence. But I have discovered in the analyses of the State Board of Health sufficient cause to lead me to think that at times even the water of Basin No. 4 was quite disagreeable.

Mr. HOLDEN. I would like to inquire whether, in clearing those reservoirs, all vegetation and stumps were either removed or covered up, or was some left exposed?

Mr. HASKELL. I suppose Mr. Holden refers to these reservoirs 2, 3 and 4. I understand that in Reservoir No. 4 the most thorough work possible was done. I think it was done more thoroughly than ordinarily would be attempted, and if ever there was a reservoir

where such work would be effective, it is that one. The whole condition was perfectly understood, and everything was done in that connection to make the waters of Basin No. 4 perfect. In basins 2 and 3 the loam was excavated within 8 feet of the high water line. As I gather from the reports, Basin No. 3 contains the poorest water at present, Basin No. 2 would come second, and Basin No. 4 the purest; but none of them, I think, contains water of such character as it is possible to secure by means of filtration. Of course all of you understand that if you take ninety-nine and a fractional per cent of all the impurities out of the water, even in Basin No. 4, the water must be better than it was before. The only question as to the necessity of filtering it is when the public get educated up to the point where they don't like water without its being filtered. There was a time when people were killed by drinking water, and they didn't complain about it because they didn't know it hurt them. They used to say about our Lynn water, that the people didn't know enough to complain about it, but after a time the people demanded better water, and the time may come when they will demand it shall be aerated, which would undoubtedly make it a little more pleasant to use.

Mr. HAWES. I would like to ask Mr. Haskell if, in studying this method of improving the quality of the water by covering the bottom of the reservoir with a layer of sand, any conclusions were reached as to the length of time the improvement will continue; that is, whether or not the effect will be permanent, or whether the idea was to provide a bottom for the reservoir which could be cleaned.

Mr. HASKELL. It is the evil effects of what may come from the organic matter which we want to protect ourselves from. Now, these evil effects are incident to the organic matter, and they can be avoided by removing the organic matter. You take a seed and plant it in the ground, expecting to get something from it, and if you plant it a certain depth below the surface it germinates, and you get the desired result. Now, here is a seed you do not want to have germinate. It is already in the soil. The only thing to be determined is the amount of covering necessary to entirely prohibit the germination of the seed. While I say a foot, I really think that six inches would be equally effective, provided that the six inches remained perfectly undisturbed, because there are very few seeds

that would come up through six inches of gravel in the short length of one season.

The PRESIDENT. Such frequent reference has been made here this afternoon to some of our basins on the Sudbury River, that perhaps it may be pardonable for me to say a word on the subject, for I have taken a great deal of interest in it for a number of years. In 1880 we first began, on the Boston Water Works, the stripping of our basins, and the treatment of shallow flowage, as we call it. I think that was the first comprehensive treatment that any storage basins had ever received, of that kind, certainly so far as I can find out; and it arose in this way. The basins had been built without any clearing to speak of at all; the trees were simply cut off, and the stumps and the swampy areas and loam and everything remained very nearly as they were originally in the basins. In the course of three or four years we began to have a great deal of trouble with our water, and it grew worse and worse. The albuminoid ammonia, which is a very fair measure of the organic matter in the water, ran up to 0.0500; it is now down to 0.0160 in 100,000, I think, as about the average. When the water absorbed all this organic matter from the soil and the roots, the amount of growth in these basins began to get very large, and that gave food for animal forms. For instance, the sponge came in very great quantities. I have seen the sponge in our Sudbury aqueduct at Farm Pond for the first two miles, from the gate house, so thick on the bottom (which had all been thoroughly cleaned six months before) that you could walk the whole distance without treading on the brick work, — great patches of sponge a foot and a half in diameter and an inch in depth; and that growth had come in six months. I could bring up a great many instances of a similar nature.

This led me, for a great many years, to devote a good deal of attention to the matter, and I have collected a mass of information which I hope to put in shape sometime for the profession. We cleaned out a large part of Basin 2 in 1880, and previous to 1883, Basin 3. Neither of those basins was thoroughly cleaned out, but they were very much improved. Down to a certain point everything was taken out, and a certain treatment was made of the sides so that there was not less than eight feet of water around them.

When Basin 4 was built the whole of the bottom was stripped, but

it was not given as thorough treatment as Basin 6 received afterwards. Basin 6 was completed about two years ago. We have a long series of very careful chemical analyses and bacteriological and biological examinations of both basins 4 and 6, covering a long period, and also of some of these other basins. The proof is conclusive to my mind that you cannot expect anything like the same improvement in water stored in an uncleaned basin that you can in one which is thoroughly treated in that way. I think very probably our treatment of Basin 6 was more thorough than necessary. That is, it hardly paid us to expend so much money in taking out the whole of the subsoil. We took out of Basin 6 not only all the material on the surface, but we took the subsoil down to two and three feet in depth. In fact, the whole of that basin is perfectly clean down to the gravel or the clay or the sand, and it is marvellous the work that basin does in the way of improving the stored water.

Mr. Haskell referred to the natural agencies at work. Now it is necessary for us to keep clearly distinct in our minds the natural agencies for improvement, and the natural agencies working in the other direction towards the deterioration of the water; and it seemed to me that perhaps for a moment Mr. Haskell got off the track there, although I may be mistaken about that. But I will give a little *résumé* of that as it appears to me. If you have the water beating on the sides of the banks which have not been treated, that action goes on for years and years. I have seen it going on after the passage of thirty years. That is to say, the banks were still caving under the influence of storms and waves, and the organic matter in the soil was going down into the water at the end of thirty years. And I have also seen after a lapse of forty years, by special examinations of areas which were shallow and which have not been treated, pretty good proof that the action of the organic matter is still going on; while in the same pond over another area where there is not this shallow flowing, it is not going on.

Now I have noticed on the sides of ponds, that while a certain amount of gravel may form, yet if you dig down into it you will find that there is loam under it, and it is only waiting for a big enough storm to be exposed and washed down. So I believe if a man builds a reservoir and waits for that kind of action to improve it, he will wait until he is a pretty old man, and that the only way to get it is by such treatment as we are carrying out on the Boston Water Works.

Now, a single word, because I think it may be useful to you and save you a good many thousand dollars if you have work under way, or if you are proposing to dig out shallow portions of your ponds, and that is, to fill those portions, instead of excavating them, with the material which comes out from further down. In that way you will kill two birds with one stone, because you will save digging out a good deal of material over the whole area. And then, if you cover the slopes with gravel, in six or eight years you will have very clean shores, and the improvement in the water will be very great.

Now there are places where you cannot treat the water in this way, — small areas, small water-sheds, where it is impossible to get large storage basins, and where you cannot provide for this wonderful system of oxidation which goes on in Nature; and there it seems to me that nothing but a filtration system will make the water safe. I have a number of small places in mind where they depend on perhaps two or three square miles of drainage area, and the water from it, not being impounded in large reservoirs where it can have an opportunity to improve, must necessarily go right down the throats of the people with whatever it contains. And anyone who has had much experience knows that there is hardly anything more unsafe to do in the world than to drink water out of an ordinary brook, even if it is in comparatively good neighborhood. The things he is liable to get down his throat would surprise him after a study through the microscope. These things, it seems to me, it is extremely important to exclude from a water used for domestic supply.

I wish to add that in comparing Basin 4, which Mr. Haskell has so highly recommended, with Basin 6, which was still better treated, interesting results are noticed. The two basins are about the same size and have about the same drainage area. One was well stripped and the other was most thoroughly stripped, and the difference in the work that those basins do is in favor of the one which was most thoroughly stripped. Whether it is enough better to pay for itself is a question to which I am going to give a little more consideration.

We have to-day going on in one of our large natural lakes something which illustrates what Mr. Haskell has spoken about; that is the sudden growths which may come up and disappear in almost a day. Uroglena are among these growths, and we have that to-day in one of our large lakes. It is simply a question of giving the water enough organic matter to produce that life, and the life is sure

to come. I knew it was coming in this case, and it was a wonder to me it didn't come before, because owing to the large amount of organic matter which was thrown into the lake recently, by causes beyond our control, by the filling of the railroad across one end of it, the organic matter was sufficient to produce an abnormal growth. Uroglena will come up and disappear in a short time. It does not appear without a cause. Water will absorb matter like a sponge, and it is only necessary to give it the organic matter in some form, and it will take it up and then you will have the result following.

I do not myself take much stock in drawing off a pond and allowing it to freeze, or anything of that kind. It does not seem to me a comprehensive treatment. It may have a certain effect, but I think in another way from what Mr. Haskell suggests. I have noticed in the case of Basin 6 and of Basin 4, which are very deep, about fifty feet, that the water at the bottom at the end of this long stagnation period in the summer has the full amount of oxygen in it; it has not been deprived of its oxygen. But you put that same water into a deep pond which has not been treated, and the oxygen will be used up and the water become offensive. But that is a subject on which more can be said by and by.

Mr. HASKELL. I would like to say, Mr. President, that perhaps you and I are on the same footing when we come to consider the question of the purity of water. The remarks I made, to which you refer, were not expressing opinions I had as to the best way of securing the purity of water, but they were describing what the natural causes were that were working in ponds. I think you will see I don't think very much of natural causes. We should not have been cleaning our ponds out if I did. I don't think the natural causes are sufficient; we got away from natural causes a long time ago, and the very best sort of work that has yet been done, as I look at it, is not quite good enough.

Mr. FULLER. Some reference has been made to the fact that if this organic matter is covered by a great depth of water it might be ineffective. I should like to inquire whether a depth of water over a quantity of organic matter really makes a great deal of difference.

Mr. HASKELL. That opens up another subject upon which there might be two or three papers written. I don't know that anyone has yet got data sufficient enough to cover that, but there will be a

paper presented before this Association a little later, by Mr. Whipple, that I think very likely will give us some points that have a bearing upon that. Of course the organisms have got to be brought to life by some influence, either by the influence of heat or light. Of course anyone knows that a thousand feet deep they could not come to life. There is a certain depth below which water stagnates, and in some ponds at a little different depth than in others. In a very wide pond, where the wind can secure a greater leverage on the water, the point of stagnation will be lower than in a small pond. My opinion would be that any point below the point of stagnation would be sufficiently deep, and it would not be necessary to dig out beyond that point. But as far as I know, this question has never been sufficiently studied to enable any of us to talk with certainty upon it. We can simply say that things point in a certain way, and while the depth will vary in certain ponds, yet I think the point of stagnation ought to be sufficiently deep, and that we need not feel obliged to clean the bed of the pond any deeper, and quite likely we need not go so deep.

The PRESIDENT. In Reservoir No. 5, which we are constructing now, and which is the largest one the city of Boston has ever undertaken, instead of digging down to clean gravel and sand we are taking out about one foot in depth all over the area. I have had a great many analyses made of the soil all over the basin, and I have found that a very large per cent of the organic matter is contained in the upper few inches, so that after you get down below, say, about a foot, the amount of organic matter which you will take out is so small we have concluded to leave it and not take out all down to clear gravel.

There are in this Basin No. 5, which covers about three square miles, some large pockets, one very large pocket, of peat, and we are going to spend a large amount of money taking that out. There are two or three other places where there is peat, and there are some large areas where it is not very deep. We have recently exposed that by cutting into it, and it is very interesting and instructive to study its formation. Under the black peat, which is perhaps a foot and a half in depth, there is a brown peat which contains a large amount of silica. It is full of grass roots, and these grass roots seem to have lost all their organic nature, and are simply like little conduits, as it were, to carry the water up to the grasses. The material is very light; you take it in your

hand and it is like unformed peat. It is very clean, it is brown in color, and it is apparently of a very peaty nature until you begin to crumble it in your hand, and then it becomes very fine. As I said before, it is completely filled with these roots, which go down three or four feet in depth. Then, under this brown material, which is perhaps a foot and a half deep, is another formation with gray clay in it, and that also has the grass roots in it. Now, the question with us to-day, and one we are hard at work upon, is whether to take out this brown material or whether to stop on top of the brown. On some other occasion perhaps I may tell you what result is arrived at, and the reasons for it.

Mr. FULLER. If it had been muck down to that depth would you not have taken it all out?

The PRESIDENT. Yes. Of course you may have muck 20, 30 or 40 feet in depth covering large areas, and in such a case I do not think you can lay down any general rule. There are still some unsolved problems in connection with this subject. It seems to me you must make a special study of each place, and where to stop and what to do depends upon a great many circumstances. But there is no doubt that in a basin thoroughly prepared by the removal of the soil, and with gravel shores around it, the water improves very remarkably, and it is exceedingly interesting to trace the different stages in that improvement. It is only necessary to keep the water there long enough for it to lose all its color. There are streams coming into Lake Winnepesaukee which are yellow as gold, and yet the water in the lake is 0.01 on our scale, almost absolutely colorless. In parts of the lake the water is from 125 to 150 feet in depth. I have had samples taken from those deep holes and found the water just as good as at the surface. It is simply due to the fact that the water stays in the lake long enough to undergo all the changes by oxidation through the action of light and air.

UTILIZING A SPRING AS A SOURCE OF WATER SUPPLY FOR A TOWN.

BY LOUIS E. HAWES, BOSTON.

[*Read June* 11, 1896.]

Mr. President and Members of the Society:

The paper which I have to present to you introduces a subject with which we are all more or less familiar; we have all seen springs, drank of their waters, marvelled at its clearness, and often looked at the boiling water and wondered just where it originated, why it appeared there and what influences were continuing its flow after brooks and streams had become dry. For notwithstanding what knowledge we may have of the subject, there is a certain mystery lurking about it that is not easy to dispel, and probably never will entirely disappear until something better than the divining rod has been devised to trace the course of the vein and outline the reservoir that supplies the spring and preserves its constancy. The divining rod may serve its purpose in the hands of certain persons and its action appears strange, yet possibly subject to scientific explanation; however, as used it only serves to deepen the mystery and in the hands of the uninitiated is certainly useless.

Webster defines a spring as "the source from which a stream proceeds; a fountain," and the name is usually given to the particular spot where the water issues from the earth and runs off on the surface; if the quantity is small and appears at many points not well defined, the term "springy" is applied to the location.

The geological conditions governing the formation of springs in which differences of altitude bear an important part largely accounts for their rarity in flat countries. As river courses are approached and the region becomes more undulating or irregular, the conditions are improved and springs occasionally occur. The usual uniformity of the substrata, and frequent non-absorbent nature of the soil are also important features determining their absence in prairie regions. As an instance of the latter condition, the water-shed of a tributary to the Little Arkansas River in Harvey County, Kansas, may be cited, which above the point where it is utilized for water supply pur-

poses has an area of thirty square miles. Comparatively little rain water is absorbed and during a freshet the creek carries a volume measuring into the hundreds of millions of gallons in twenty-four hours, while in a dry season there is no running water for many days. Springs are seldom heard of, and the only one examined by the writer was found to be weak and intermittent in action. The soil of this water-shed is considered a little less impervious than the average in that region, for it is not an unusual condition in the West and has a marked effect upon the rivers subject to its influence. As the rainfall frequently reaches flood proportions in a short time, the water quickly travels from draw, to creek and stream and thence to the river, where the aggregation of debris washed along often entirely covers its surface, or merely permits a patch of clear water to show here and there; while the rise is rapid and considerable, and if occurring in this part of the country would be thought phenomenal.

The Verdigris River, which flows through a prairie country and empties into the Arkansas River, has a high and low water level differing by forty feet, and is one of the many rivers the soil of whose water-sheds is of this character.

Springs are also seldom or never present within large areas whose surface and sub-formation is of a uniformly porous nature, constituting locations adapted to the collection and storage of water in the ground, which in consequence of its non-confinement by any impervious inclined strata above, assumes a surface that is nearly level.

An extreme case of such formation can be seen at the broadened end of Cape Cod, where for an area of seven square miles and for a depth considerably below mean sea level the material is composed entirely of sand, through which the water moves very freely and whose character and uniformity of grains renders it almost a rival of the beautiful sand which comes from Horne Island in the Gulf of Mexico. Although hills and valleys abound no springs nor brooks exist, but there is a lake of water beneath the surface which only appears where the latter is depressed below the water table forming ponds.

Springs may be said to be present, however, on the beach at low tide when the ground water has an opportunity to escape, but they are soon nullified and stopped by the incoming tide, to appear again when the tide recedes.

Where a porous area is elevated above the surrounding country,

adjoins lower land, or is cut by streams so that the ground reservoir can overflow or find relief at a lower level, the conditions are suitable for the appearance of springs on its outskirts and we find these places their prolific feeders. Examples are found in this State in the territory called Needham Plains in the town of Needham, elevated seventy or more feet above the Charles River and composed of porous sand or gravel, and the sandy plains east of the Connecticut River in the vicinity of Springfield. The structural conditions prevalent in countries that are generally hilly are usually found to be most suitable for producing springs, and New England seems to be especially favored.

Exactly why a spring appears at any particular place is not always apparent or subject to conclusive demonstration without investigation on an elaborate and expensive scale. The most plausible and comprehensive reason that is usually given is that "the ground water in moving down a valley by the action of gravity encounters an obstruction or dam in its course which forces the water to the surface where it appears as a spring." There are other well recognized and fully as important factors which may be mentioned as follows: —

Differences in elevation between the absorbent or reservoir-forming portion of the water-shed and portions lower down, constituting the head; approach to the surface of the water-bearing strata or vein in which the water moves most rapidly, in consequence of the prominence of the bed rock or impervious strata below, or the rapid inclination of the surface above; the presence of boulders or ledge croppings at a location that is otherwise favorable, with the usual accompaniment of breaks and flurries in the stratification; and the perviousness of the overlying strata at a favorable point which offers little resistance to overcome the head.

As is very well known, the stratification of the glacial drift is decidedly varied and replete with abrupt changes; this is found to be particularly true where springs appear, so that in a consideration of the controlling influences, little more than a statement of the general nature of the soil and a suggestion as to the main elements is possible without special data.

The relations of some of these factors in specific cases is shown by the accompanying diagrams which have been prepared from information gained through the aid of test wells and excavations in the

regular course of practice, but without reference to its use for the present purpose. They represent the conditions in each place as closely as possible from the data available.

Fig. 1 is a longitudinal profile and section representing a portion of the upper part of the valley of Vine Brook in the town of Lexington, Mass. The water-shed of the brook above the point marked *c* has an area of about half a square mile, and above *b* one quarter of a square mile. The valley has no well-defined absorbent area of large extent above these points; the porous formation, of which there is a fair quantity, is distributed in small tracts on the main slopes and intervening undulations. Springs occur at the points marked *a*, *b*, and *c*, and it is interesting to note their progressiveness as the area of the water-shed increases; the one at *a* being an intermittent spring, the one at *b* a small perennial, and the one at *c* a large perennial. Pervious material is represented as shown at *d* in the section, impervious as at *e*, muck as at *f*, and rock as at *g*.

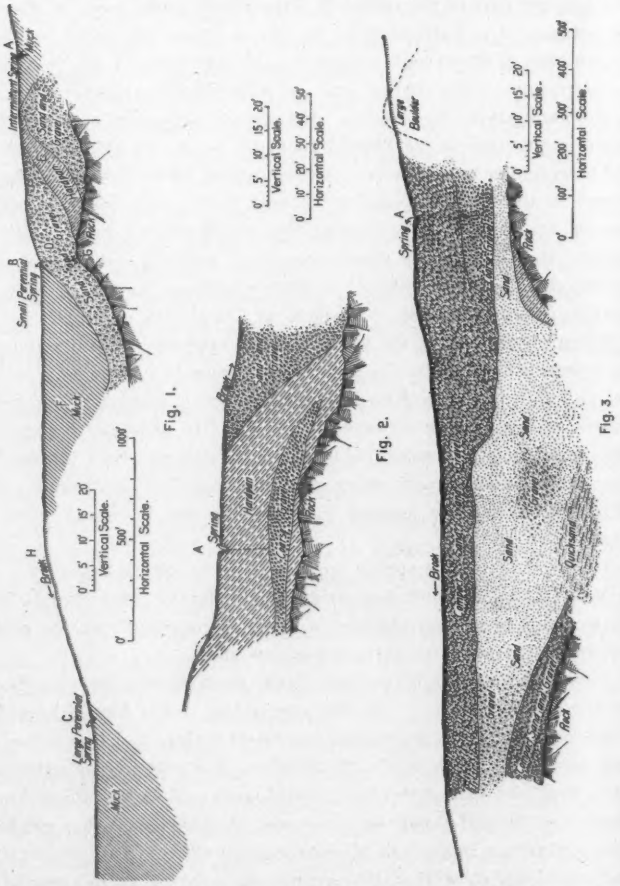
The ground water in the valley above *a* appears to be intercepted in its downward course by the impervious strata at *e*, causing it to find its way into the rock beneath, which is of a seamy, disintegrated nature, offering ample opportunity for the free passage of water and also permitting an outlet below at *b*, where the rock approaches nearest the surface and where the superimposed sand and gravel offers little resistance against the pressure that is acting upon the water.

The location of this spring appears to be determined also by a natural dam at *h* some 1300 feet away, for the line of saturation between the two points is only slightly inclined, is practically at the surface and but little below the elevation of the spring.

A marked feature of this profile is the succession of depressions containing muck deposits. The first one is four or five hundred feet long and 5 or 6 feet deep, the second one about a thousand feet across and over 12 feet in depth, while the third one is a half mile in extent and has a depth of 40 feet or more. Geologists tell us that these depressions once formed ponds or lakes and that the muck has gradually grown until the basin has become entirely filled. Our observations and soundings show that this growth is in progress in many of the ponds, lakes and reservoirs now used for water-supply purposes. Constant alluvium washings, debris, leaves, vegetable growths within the water and upon the bottom, accumulate in the muck-forming pro-

cess that promises well for the ultimate conversion of the sheet of water into a meadow.

Fig. 2 is a sectional view at the location of the Porter Spring in the town of Avon, this State. The principal absorbent area is ele-



vated from 15 to 50 feet above the spring, is of considerable extent not far away, and the brook of the valley is about 450 feet from the spring. The water issues at the point marked *a* in the figure and

the principal factors determining the location, appear to be the head or pressure and the interruption or termination of the strata carrying the water which is occasioned by the impervious strata.

The water-bearing material is a coarse, reddish gravel 12 feet below the surface, which disappears beyond the spring and is overlaid by a strata of hard pan which also dips off a short distance away beneath the sand and gravel that follows. The bed rock is prominent, approaching within 16 feet of the surface and dropping off below the spring, as in Fig. 1. As boulders occur in the upper strata, weak places were no doubt present which permitted the water under pressure to force its way through. It is significant regarding the head and usual tightness of the hard pan, that when the well for utilizing the spring as a source of supply for the town was constructed, the walls were built up so as to store the water three feet higher than before, which was accomplished, and the water in the well stood five feet higher than the surface of the meadow 75 feet away, the site of the original spring having been previously sealed over.

Fig. 3 represents the formation in the vicinity of the Colburn Spring at Needham, Mass., which is an unusually large one. Although hard pan and clayey material exists in parts of the water-shed, the major portion is of sand and gravel formation of various degrees of porosity. The principal area suitable for ground storage is half to three quarters of a mile from the spring and elevated 50 to 70 feet above it. As shown in the figure, the spring appears at *a* where the bed rock is prominent, approaching within 19 feet of the surface, and a very large boulder or ledge cropping occurs a short distance above, which, as found by excavations, apparently disturbed the regularity the of stratification.

The water-bearing material is 14 feet below the surface and consists of a mixture of coarse gravel and disintegrated rock or boulders, with a finer material of a somewhat similar nature above and sand beneath, while the surface strata is compact sand and gravel. Small pockets of sand and clay were found irregularly placed at the spring location. In the valley below, a decided depression occurs in the sub-formation, which is filled with sand and gravel, varying from quicksand to fair-sized gravel. The main factors in this case are the compactness of the sand and gravel immediately below the spring, the diminution or termination of the coarse strata or vein and the great pressure from the storage reser-

voir, combined with the nearness of the water-bearing strata to the surface and the presence of malformations. There are no indications of influencing obstructions further down the valley, the brook in a distance of 1400 feet having a gradual fall of 8.5 feet.

The supply well constructed at this place permitted the water to overflow at an elevation 2½ feet higher than the average level of the original springs, and 4¾ feet above the bed of the brook adjoining.

Where springs have been taken by right of eminent domain and the damages for so doing determined in court, very interesting questions arise as to their capacity, permanence, possibility of contamination, the value of water, relative value of the spring in question, rights of the owner to the exclusive use of its waters, and even questions affecting its genuineness, as in a case recently tried in the Superior Court for Norfolk County, Mass.

As no two cases are alike and this one has been settled, no harm can result in describing some of the salient features. The trial resulted from a suit for damages in the sum of $25,000 for the taking by the Commonwealth of Massachusetts of the Blue Hill Silver Spring in the town of Milton, which is located within the Blue Hills Park Reservation. In making an examination of the spring, its surroundings and water-shed, for the purpose of estimating its value, it was found to be situated upon the southerly side of Great Blue Hill; the water-shed having comparatively steep slopes largely composed of a stony, rocky formation, constituting a quick shed without favorable conditions for producing springs. The spring well is 43 feet from the brook draining the valley, 3 feet 6 inches in diameter and 5 feet 6 inches deep. There is no overflow, but the water moving in the same channel that supplies it issues from the ground 40 feet away as springs.

The conclusion was early reached that this water was from the surface, escaping from the brook somewhere above the spring-well and finding a channel through the rapidly inclining stony formation to appear below as springs. Measurements and tests were made to determine this, and it was found that at a point on the brook 400 feet above the springs, the quantity of water flowing in the brook equalled the quantity issuing from the springs below, plus the quantity flowing in the brook opposite the springs; showing that the brook lost an amount equal to the flow of the springs, somewhere between

the places measured and probably at a comparatively flat portion of the brook just below the uppermost point.

These measurements, together with results of a corroborative nature from other tests, demonstrated that the spring water was simply brook water a little earlier in the day, and from the nature of the intervening formation subject to practically the same influences. However, both the brook water and the water from the well were excellent in quality at the time of the examination, and possibly more suitable for table use than many waters used for the purpose that come from permanent deep-seated springs.

In considering the possibility of utilizing a spring as a source of water supply for a town, the question of purity and freedom from possible future contamination having been settled satisfactorily, considerations of the size or flow of the spring, its permanence, seasonal variations, the area and nature of its water-shed, and its location and relation to other sources of supply naturally follow. To serve as the entire supply a spring must be of unusual size, or the number of inhabitants to supply correspondingly small; when neither of these conditions is fulfilled except in a moderate degree, a spring favorably situated may be a valuable adjunct to a supply from another source, either as an increase to the existing quantity or for the purpose of imparting an improvement to the quality, which is usually the result of such an admixture.

The number of springs that may be found in nearly every town in New England is almost surprising; no less than seven of fair size were examined by the writer in one town during preliminary investigations for a water supply, so that one almost invariably hears of certain unfailing springs that "never go dry," to use a common expression, which are suggested as suitable for public use. Most of them are either too small, isolated, or unfavorably situated to be available for a town supply; but all have their enthusiastic admirers, and it is not to be wondered at, for with a spring are ever associated thoughts of an ideal drinking water.

When the possibility of having such water for every-day domestic use becomes a reality, to draw it from a faucet like common river or pond water in a large city, and at an expense of less than four tenths of a mill per gallon, instead of from three to ten cents, as is paid for table water by the jug or carboy, it is a matter for congratulation, and the community possessing it is indeed fortunate.

The size or flow of a spring depends upon the area of the absorbent surface, the storage capacity in the ground, the head or resultant velocity of the flow, and the capacity of the channels through which the water passes, but is always subject to direct variation with the rainfall. The main storage reservoir may be near or distant from the spring, but seldom or never surrounds it and is always above and usually some distance away. The water reaches its outlet through the channel offering the least resistance, which may be a very porous strata, a particularly open portion of such a strata, fissures in the rock, or the broken stone resulting from the disintegration of rocks and boulders. Where the water moves most rapidly in such channels it constitutes a vein, whose course may be very irregular, and which is therefore often difficult or impossible to find from the surface.

The capacity of a spring in its normal condition can be readily ascertained by measuring its natural flow; if these measurements are continued at regular intervals over long periods of time, including seasons of extreme conditions, the seasonal variations will be determined. Such records are rarely kept however, their importance seldom being realized until the spring is utilized and the normal conditions changed.

The capacity of a spring after its resources have been developed, or rather the capacity of the well or wells constructed for its development, differs materially from its normal capacity. The channel through which the water finds its way to any particular spring may be only one of the various outlets of the storage reservoir; the other outlets may appear at the surface as springs in other parts of the water-shed of the stream draining the valley, or may continue underground in other courses to ponds and rivers below. Consequently, when the water is drawn down at any spring to a lower elevation than that at which it naturally appears, the head is increased, causing a corresponding increase in velocity of the inflowing water, which results in a greater discharge.

When the surface of the water is first lowered, this increase in quantity may be partly ascribed to the amount stored in the immediate vicinity of the well; after a while this is exhausted, but the changes in inclination of the lines of saturation have become far reaching, and water hitherto moving in other channels is diverted by the changed conditions and follows the new inclination. If the

draught is continued the storage reservoir will be affected, its surface lowered or inclination changed, and other outlets will lose a part or the whole of their flow, which is thereby contributed to the well being draughted upon. The latter condition was illustrated during continued pumping from the Needham well while in process of construction, with occasional interruptions. The flow of the Hicks Spring half a mile away was diminished perceptibly and the action of a hydraulic ram affected, which was particularly noticed to occur when the pump at the well was in operation.

This spring is in a direction from the well nearly at right angles to the course of the brook. There are two brooks between the well and spring, the latter supplies a third and would naturally be considered in a different water-shed, although the dividing line is not pronounced. From its location and the circumstances mentioned it is probably fed by the same reservoir. It does not follow, however, that the same or similar conditions always exist concerning any two springs that may be somewhat near each other, or even in the water-shed of the same brook, for their particular water-sheds may be distinct, separated by a barrier and uncommunicable, as might be the case with two springs on opposite sides of a wide valley.

The location of the Seaverns Spring in Lexington, Mass., is an example of the latter situation, being at the toe of the slope on the opposite side of the valley from the spring wells and pumping station of the town supply, with a deep muck deposit intervening. No records have been kept that would determine beyond question that long-continued pumping on the wells does not affect the flow of the spring, but from such observations as have been made it is probable that the spring is not seriously affected, if at all.

In a preliminary study of the probable quantity to be depended upon, it would be on the safe side to consider a spring well supply on the basis of an ordinary ground water at the place under consideration, and estimate the quantity in accordance with the method described in Mr. Frederick P. Stearns' paper on "The Selection of Sources of Water Supply" under the heading "Quantity of Ground Water" printed in the journal of this Association for March, 1892.

While it is possible that a spring well as usually situated may not furnish as much water as a well located in open porous material with a direct water-shed of the same area, it is very probable that it will

furnish more water than could be expected from the same water-shed in which it is located, were the spring and its supply channels absent.

Mr. J. T. Fanning, in his treatise on Hydraulic and Water Supply Engineering, states that "From springs, with the aid of capacious storage reservoirs, it might be possible to utilize fifty per cent of the above (referring to accompanying table) volume of percolation. From wells, it would rarely be possible to utilize more than from ten to twenty per cent of the volume."

Experience teaches that the best place to secure a ground-water supply from a valley containing a large spring is at the spot where the spring appears, for where nature has already provided main arteries we may expect the freest flow and the most complete connections with different parts of the water-shed. Just what form of construction is most advisable will be determined by the existing conditions and exigencies in each case, but will not differ materially from that usual with ground-water supplies. The formation and distance to bed rock at springs is usually not well adapted to the application of a pipe well system, and a large circular well will be found best in most cases. A direct suction connection from pumps to well is more economical to construct than a conduit, and if the distance is not too great will ordinarily be found preferable for that reason. If a conduit is used it must be of ample size and built so as to utilize the full depth of the well to get the best results.

Considerations of economy in pumping, and a reserve for fire purposes other than that afforded by the customary reservoir, usually determines the advisability of additional resources before the ultimate capacity of any ground supply dependent upon a limited rate of infiltration is reached. With spring wells supplied through definite channels, the rate of inflow is largely limited by the capacity of the channels, and may therefore be slower than with a well having a direct water-shed of porous material, but for that reason the supply may be more permanent, as the rapid exhaustion of the reservoir is thus prevented.

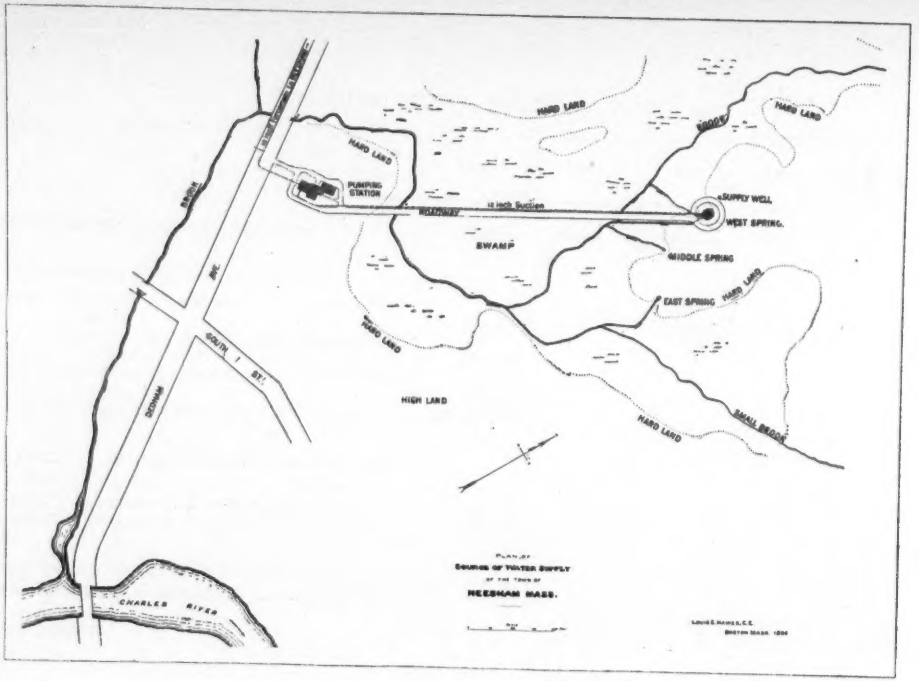
For the purpose of affording opportunity for comparison with other springs, the following data compiled from observations made before and during construction, and from the pumping records since, is given concerning two springs that have been utilized for town supplies six and five years respectively.

PORTER SPRING, AVON, MASS.

	1889	1890	1891	1892	1893	1894	1895
Rainfall (Chestnut Hill Reservoir) in inches .	54.79	50.21	49.63	42.27	46.71	38.17	45.93
Observations before utilizing spring.							
Natural flow, minimum in gallons per twenty-four hours	43,056	–	–	–	–	–	–
" " average in gallons per twenty-four hours	49,680	–	–	–	–	–	–
" " maximum in gallons per twenty-four hours	70,992	–	–	–	–	–	–
" " average in gallons per year .	18,133,200	–	–	–	–	–	–
Pumped from pipe wells during fifty-three hours' trial, in gallons per twenty-four hours	243,000	–	–	–	–	–	–
From pumping records after utilizing spring.							
Daily average for the year	–	12,982	39,945	41,168	55,124	59,728	61,921
Maximum pumping, ten consecutive days, in gallons per twenty-four hours . . .	–	27,752	44,484	82,807	81,455	101,313	75,945
Maximum for one day in gallons . . .	–	77,589	84,811	120,045	122,974	143,970	135,531
Time pumping maximum quantity . . .	–	2h. 30m.	2h. 30m.	3h. 25m.	while painting standpipe.	4h. 40m.	while painting standpipe.
Total gallons pumped	–	4,738,609	14,580,106	15,026,291	20,120,272	21,800,682	22,601,234

COLBURN SPRING, NEEDHAM, MASS.

	1890	1891	1892	1893	1894	1895
Rainfall (Chestnut Hill Reservoir) in inches . .	50.21	49.63	42.27	46.71	38.17	45.93
Observations before utilizing spring.						
Natural flow, minimum in gallons per twenty-four hours	246,816	–	–	–	–	–
" " average in gallons per twenty-four hours	274,320	–	–	–	–	–
" " maximum in gallons per twenty-four hours	310,536	–	–	–	–	–
" " average in gallons per year . . .	100,126,800	–	–	–	–	–
Pumping from well excavation continuously 21.5 days.						
Minimum quantity in gallons per twenty-four hours .	415,152	–	–	–	–	–
Average quantity in gallons per twenty-four hours .	440,479	–	–	–	–	–
Maximum quantity in gallons per twenty-four hours .	519,840	–	–	–	–	–
From pumping records after utilizing spring.						
Daily average for the year in gallons per twenty-four hours	–	25,419	64,654	106,149	112,217	139,099
Total gallons pumped	–	9,278,008	23,663,503	38,744,726	40,959,255	50,771,384


HARD LAND
BOGGY
HARD LAND
PUMPING STATION
HARD LAND
SUPPLY WELL
12 Inch Suction
ROADWAY
WEST SPRING.
SWAMP
MIDDLE SPRING
EAST SPRING
HARD LAND
BOGGY LAND
HIGH LAND
HARD LAND
SMALL BROOK
BROOK
NEW
SOUTH ST.
NEEDHAM
CHARLES RIVER
Plan of
Sources of Water Supply
of the Town of
NEEDHAM MASS.
Louis E. Howes, C.E.
Boston Mass. 1904

The Porter Spring constitutes the present supply for the town of Avon, Mass., having a population of 1,626. The water-shed of the brook draining the valley has an area above the location of the spring of about 0.5 of a square mile, with possibilities for a reserve supply; and the formation of a considerable portion of the territory is of a fairly absorbent nature, 30 or 40 acres tributary to the spring being especially favorable.

The table shows that during the last three years the quantity of water pumped exceeds the average natural flow as observed in 1889, demonstrating that the normal capacity of a spring is not the measure of the capacity of a well at the same location, the difference in quantity being made up from the storage reservoir. In 1894, the year of least rainfall, the quantity pumped was but six per cent of the total rainfall, indicating that much water runs to waste during wet seasons.

The minimum natural flow was measured after a period of nineteen days, when the rainfall was so slight that probably none of it reached the water table; and the maximum following a fall of 2.44 inches, showing the variations springs are subject to in direct consequence of variations in the rainfall.

The quantity pumped during a short preliminary trial of fifty-three hours was an aid in studying the source, and indicates pumping possibilities in a similar season when the storage reservoir has not been drawn upon for too long a period to permit of it; as does also the quantity pumped at a trial of the permanent pumping plant for determining its capacity per minute and steaming qualities, at which time 103,555 gallons were pumped into the stand-pipe in a run of two hours and forty-three minutes.

The Colburn Spring supplies the town of Needham, Mass., which has a population by the 1895 census of 3,511. The brook near by has a water-shed above the spring of about 0.9 of a square mile, which is particularly adapted for absorbing a fair percentage of the rainfall.

It is evident from the Needham records that the water required in 1895 was a little more than one half the natural flow of the spring, and that the maximum demand has not required a draught upon the reserve in the main storage reservoir, 251,102 gallons being the maximum pumping for one day in 1894, the year of low rainfall.

The greatest natural flow observed in 1890 was on April 10, nearly an inch of rain having fallen the day before, and the least flow on

Aug. 25, after nearly three months in which there was a deficiency of rainfall, and in a season when it is doubtful if the water table received any replenishment.

The quantities pumped from the well excavation during construction are of interest, as the pumping occurred immediately after the deficiency in rainfall before mentioned and when little or no water was running in the brook above the spring. The pumping covered a space of two and one-half months, and during three periods was continuous; one of 11 days, one of 21.5 days, and the third of 12 days, with a dry spell of two weeks occurring during the longest period. The least quantity pumped was during three days at the end of the dry spell, and as given in the table was 415,152 gallons, which amount represents twenty per cent of the average daily rainfall for the twelve months preceding.

By the third day after pumping ceased, at the end of this space of two and a half months, during which time the quantity pumped and the natural flow exceeded 23,000,000 gallons, the spring had resumed nearly its usual flow.

The Colburn Spring, originally consisting of three distinct springs within a radius of 110 feet of each other and marked East Spring, Middle Spring, and West Spring on the plan accompanying, is not far from the Charles River. This locality is near the middle of a long detour which the river makes about the town, almost semi-circular in shape, for a distance of about nine miles. The town is practically enclosed by it on three sides, the main villages being situated near the centre of the bow on elevated land about a mile from the river. The water-shed of the brook is east of the villages and comprises a portion of the Needham plains before referred to, with an absorbent area of a hundred acres or more where the formation is very porous and the water table twenty-five or thirty feet below the surface.

The location of the works is particularly fortunate in possibilities for the future, when the town outgrows the supply from the well; not the least of which is the opportunity to obtain a ground-water supply near the river; legislative right to a daily quantity of 500,000 gallons from it having been obtained by the town.

The supply works were designed with a view to future additions, the pumping station being located nearly midway between the spring and the river. This renders the connection between pumps and well longer than ordinarily advisable for a direct suction. It was

determined by considerations of the best location for the station, present and future, together with the fact that the extra friction in the suction pipe would be of little consequence in this case, as there is a back head of two feet on the pump discharge valves when the well is full, and the maximum lift is but 19 feet. The suction pipe is 12 inches in diameter, 970 feet long and laid on a true grade.

The spring well is circular, 22 feet in average diameter, 24 feet deep, built of open-jointed rubble masonry with a lining of brick laid in cement mortar, for the upper 18 feet, and is surmounted by a conical shingled roof. It was built at the largest and highest of the three springs and the sites of the other two were sealed over with concrete, while the water was kept down by pumping from the well. The outlet is a foot and a half below the top of the well which overflows between times of pumping. Access from the street is by a roadway built around the station and across the meadow.

The pumping plant is in a substantial brick building, is operated by steam, the machinery is duplicate throughout, designed for economical operation, and has a total capacity of one and a half million gallons in twenty-four hours. The plant is connected with the distribution system three quarters of a mile away by a 10-inch force main.

DISCUSSION.

Mr. Fuller. I would like to ask Mr. Hawes whether he tested the temperature of what appeared to be the spring water, in the case which he mentioned at Blue Hills, and compared it with the temperature of the brook water.

Mr. Hawes. That was one of the corroborative features. I found the temperature of the water in the well to be 42° F., which would indicate that the water came from the ground near the surface, as the temperature of springs is nearly 50° the year round. The tests were made in the winter time when the temperature was down below freezing; between zero and freezing all the time. It was also found in pumping out this well, that the temperature of the water instead of becoming higher as one would ordinarily expect with deep water, lowered a little; showing that the temperature of the water in passing from the brook to the well was raised; the temperature of the water in the brook being below that in the well.

RECENT SPECIFICATIONS FOR PUMPING ENGINES FOR THE WATER WORKS OF THE CITY OF ST. LOUIS, MO.

DISCUSSION BY F. W. DEAN.

[*June* 11, 1896.]

I have been requested by your president to discuss the specifications for two pumping engines for the city of St. Louis which have recently been issued. The specifications are the work of Mr. M. L. Holman, Water Commissioner of St. Louis, and a member of our Association. They are for vertical triple-expansion engines of 15,000,000 gallons capacity in twenty-four hours, and bear the same evidence of care and ingenuity in their preparation that has characterized all of the St. Louis specifications since 1889.

Mr. Holman has well-defined ideas as to what is desirable in a pumping engine, and the specifications are so prepared as to prevent their evasion. They are so ingeniously interwoven with conditions, and so strongly tied together, that Mr. Holman is fond of characterizing them as being "loaded." They are among the best ever issued.

In the desire to make a cheap engine a designer may think that he will design a small engine and run it fast, when he notices that the specifications say that the plunger speed must not exceed two hundred feet per minute, which is very slow. If he then thinks that he will make the plungers of shorter stroke than the steam cylinders in order to make the pumps short and cheap, and the steam cylinders small in diameter, he finds himself balked by the clause that states that the diameter of the plungers is not to exceed forty-four per cent of the stroke. He finds, also, that the minimum area of the water way through the pump valve is stated, so that he is unable to economize in valves, nor in pump cross-section area, in the vain hope of making a less costly design than his competitors. About this time the designer concludes that he will design an engine as Mr. Holman wants it.

Besides this, the successful bidder of the previous set of engines for the same place finds that these specifications differ from former ones sufficiently to prevent his using his old patterns, and thus the

work is thrown open to everybody, giving the city whatever advantage may come from this.

An acquaintance with the specifications issued for a number of engines for the St. Louis water works, beginning in 1890, shows that the Holman "idea," if I may so characterize it, is slow speed for everything, — for moving parts of the engine, and for water. This is, in itself, from various points of view, advantageous, and contributes to peace of mind. When an engine contract is open to competition, and the lowest bid is to be accepted, as is always the case at St. Louis, slow speed is comforting, for an unskilful designer is far more likely to be successful with slow speed than with fast.

In connection with this, however, it is undoubtedly a fact, that in the hands of a skilful designer a pumping engine can run two or three times as fast as the St. Louis engines are to run, and with fully as much satisfaction and durability. The secrets of this, if they are secrets, are large water ways, large suction air chambers, rubber valves, small lift of valves, and large discharge air chambers. Looking a little beneath the surface, this means quick-moving machinery with slow-moving water, and great elasticity of cushion for the water. Moreover, the elastic cushions should be as near the seat of disturbance as possible.

There is ample evidence of the truth of this theory, for there are many pumping engines, having the above qualities, that have actually been improved in working by being speeded up.

It should not be overlooked, however, that these engines can be run faster than the stated speed and thus become engines of greater capacity, which may be very advantageous to the city under some circumstances.

There is a disadvantage in making as powerful an engine as the St. Louis engines are to be, slow running, on account of their enormous size. In this case the horse-power of each engine is 900 at the steam end, which is greater than in most other cases. This requires a low-pressure cylinder nearly 96 inches in diameter of bore. If the plunger speed could be made 400 feet per minute, the diameter of the low-pressure piston could be 68 inches, which would lead to considerable peace of mind, also, especially to the foundryman who casts the cylinder.

Not a little of the interest attaching to these engines lies in the fact that they are to pump directly into the city mains, and that they

are to have relief valves to discharge their whole capacity back into the suction pipe when the mains cannot receive it.

It is customary to build a masonry foundation from the bottom of the pump up to the bedplate of the engine, but in this case the iron work is to begin at the bottom of the pit, which is 36 feet deep. This is an interesting departure from ordinary practice, but not without precedent. It is advantageous in taking up less room than masonry and in less obstruction of the light, and is probably cheaper than masonry.

After these engines are erected, all parts containing water are to be subjected to a pressure of 200 pounds per square inch. This will of course test the principal reciprocating parts, and this test is a very important feature.

The duty trial is to be of twenty-four hours' duration, and the duty must be guaranteed to reach 135,000,000 ft. lbs. per 1000 lbs. of steam consumed, which is the highest guarantee ever required, so far as I know. Nevertheless, there ought to be no difficulty in obtaining this duty.

It is well known that when engines are started large quantities of oil are used, and doubtless Mr. Holman has found that if the city pays for the oil it is used extravagantly. To overcome this expense to the city, the specifications require the contractor to furnish all oi and grease used during the first six months.

There is only one more point that I wish to refer to, and that is, if the duty of the engine falls below the guarantee, the contractor is to lose at the rate of $2,000 for each 1,000,000 ft. lbs. that the duty falls below, and is to receive a bonus at the rate of $1000 for each one million that it surpasses the guarantee.

This is due in equity to both parties, and will bear a little discussion. If a guaranteed result is not accomplished the purchaser is not receiving that to which he is entitled, and thereby is subjected to an annual expense of which he is in no way the cause. He should therefore receive from the contractor, or withhold from him, a sum of money, which put at interest will yield him the extra cost of running the plant. This will make him just whole. In other words, the contractor should lose the capitalization, at the ruling rate of interest, of the annual extra cost of running the plant, due to the inferiority of the engine.

In the other case of an excess of duty, as this has cost the con-

tractor nothing, no reason can be given for paying a bonus, but he cannot pay the whole capitalization of the annual saving produced by surpassing the guarantee, for then he would be no better off by having the better engine. He can, however, well afford to divide this equally between himself and the contractor, and thus hold out an inducement to furnish an extra good engine.

SPECIFICATIONS FOR HIGH SERVICE PUMPING ENGINES NOS. 9 AND 10, ST. LOUIS, MO.

(The contract and general clauses are not printed herewith.)

SPECIFICATIONS.

Work to be done. 1. The work to be done consists in making the design, furnishing general and detail drawings, constructing and erecting complete in place, ready for operation at High Service Pumping Station No. 3, St. Louis, Mo., two vertical triple-expansion condensing pumping engines. Each engine shall pump fifteen millions U. S. gallons of water in twenty-four hours.

GENERAL DATA.

Water Pressure (discharge pipe gauge)	125 lbs.
Steam " (at throttle)	125 "
Elevation Bottom Pump Pit (City Datum 100) . . .	89.56 feet.
" Engine Room Floor	117.56 "
" Water in Wet Well (Approximate) . . .	110 "
Dimensions of Pump Pit	56 x 57 "
Summer Temperature circulating water about . . .	80° F.
Winter " " " " . . .	40° F.

PLANS.

Working Detail Plans. 2. A complete set of accurate and distinct detail working tracings, made in accordance with the general plans submitted by the Contractor with his proposal to the Board of Public Improvements, shall be furnished by the Contractor and submitted to the Water Commissioner within six months after the award of the contract.

3. The tracings shall be of uniform size — 25½ x 39 inches — and shall have a clear margin of at least ⅜ of an inch.

4. The kind of material to be used in each and every part of the construction shall be clearly denoted in the tracings by different section lining or by distinct lettering.

5. The tracings shall show complete sectional outline and plan views, giving all necessary dimensions and thickness of metal, radii of fillets and roundings in the various parts of the construction in plain and intelligible figures, and shall definitely state in printed letters, at all surfaces and details, the name of the parts and the kind of machine work and finish to be put upon them, thus enabling the machinery to be built and completed exclusively from blue prints taken from the tracings.

6. There shall be separate tracings showing the valve motion complete.

7. The tracings will be examined by the Water Commissioner, and if found in accord with this contract and specifications will be approved; any change found necessary shall be at once made by the Contractor to the satisfaction of the Water Commissioner.

General Working Plans. 8. The Contractor shall also, within four months after the award of the contract, furnish accurate and workmanlike general tracings, made in accordance with the drawings submitted by the Contractor with his proposal, and filed in the office of the Board of Public Improvements.

9. These general tracings shall show the position of the engines in the pits, with all floors, girders, platforms, stairs, galleries, railing, pipes, stop valves and all appliances complete, giving all general dimensions required in the erection of the machinery.

Change of Design. 10. If, during the construction, it be found expedient or necessary to change or modify the design of any of the details of the engines, working drawings showing the proposed changes shall be submitted to and approved by the Water Commissioner before any change is made.

11. All drawings rendered in any way incorrect through changes or modifications must be completely replaced by new tracings.

Book of Finished Drawings. 12. Before the final payment for the engines, the Contractor must furnish and deliver to the Water Commissioner a book of complete general and detail drawings of all parts of the engines and appurtenances, as built and erected.

The detail drawings shall show all details entering into the construction in sectional outline and plan views, with all dimensions

plainly written in neat and intelligible figures, and names printed at every detail, the kind of material used, and the finish of the various parts and surfaces.

The general drawings shall show the engines in position in the pump pits in at least four different views, viz.: Sectional side elevation, sectional end elevation, contour or outline end elevation and plan, and shall give necessary main dimensions, thickness and kind of metals, location of foundation bolts, and all important sizes of the machinery as erected.

These general and detailed drawings shall be made on mounted double Elephant paper of a size of 25½ x 39 inches inside the margin lines, strongly and substantially bound in book form, with the name and date of the engines printed in gilt letters on the covers of the book.

All drawings shall be accurately and neatly executed in ink, in a workmanlike manner and to an appropriate scale. All sheets shall be uniformly lettered and consecutively numbered, and provided with proper titles.

DESIGN.

General Features.

Pit. 13. The two engines shall be designed to be operated independently in the south pit of High Service Pumping Station No. 3, and aligned as shown by the plans on file in the office of the Water Commissioner.

Especial attention must be paid to the fact that the engines will be used for direct-pressure service.

14. The engines shall have ample room around all their various parts for access and maintenance.

Suction. 15. The height of the water in the wet well will depend upon height of water in conduit, which will approximate an elevation of 110.

Steam. 16. The engines shall be designed for an initial steam pressure of 125 pounds per square inch, and a water pressure of 125 pounds per square inch.

Plunger. 17. The pumps shall be designed and constructed to deliver the stipulated quantity of water at a plunger speed which will insure a smooth and effective action of the pump-valves, and all working parts of the machinery, but in no case shall the diameter of

any pump plunger exceed 44 per cent of its stroke, or the plunger speed exceed 200 feet per minute.

Balanced. 18. The arrangement and construction of the engines shall be such that they will give equal steam cards from each cylinder on the up and down strokes.

Reliability, etc. 19. The engines shall be designed and proportioned to have great working strength, stability and stiffness, and ample space around all parts for erection, repairs, lubrication, inspection, and adjustment.

Engines Self-Contained. 20. The engines shall be self-contained. That is, the bottom bed-plates shall rest on bottom of pit, and all framing be carried up with cast-iron columns thoroughly cross-braced.

Height. 21. The steam cylinders and the regulating mechanism of the cut-off and valve motion shall be placed entirely above an elevation of 120 feet above datum.

Frame. 22. The pump chambers and steam cylinders shall be rigidly connected and supported through the intervening frames and columns to make the whole construction of ample stability, strength, and stiffness.

Plungers. 23. Each engine shall have vertical steam cylinders and single-acting outside packed plungers, and no construction will be allowed requiring internal stuffing boxes, glands, or water packings in the pumps. All stuffing boxes shall be readily accessible for inspection and tightening up, while the engine is running.

Removal of Parts. 24. The machinery shall be so constructed that the pump chambers or any important part or piece can be easily removed to such position that it may be hoisted out of the pump pit without necessitating the frame and fixed parts being taken apart or removed.

Condenser. 25. Each engine shall be provided with a surface condenser, of appropriate size and construction to maintain a steady vacuum, and designed to directly utilize the water received by the main pumps for condensation of the exhaust steam.

Attachments and Appurtenances. 26. The Contractor shall furnish and put up all pipes, valves, oil cups, drip pans, fittings, and fixtures required to make the construction complete inside the engine room and pump pit, and shall make connection with steam main on east wall.

Appearance. 27. The various parts of the machinery shall be of

plain shapes and forms, adapted to their specific purposes, insuring great strength and reliability with good mechanical effects.

Frame and Fixed Parts.

Frame. 28. The framing shall be designed to have great stiffness and weight, so that it shall withstand all working stresses with the minimum vibration. All bed plates or sole plates shall have ample bearing surfaces to safely distribute the working pressures.

Anchor Bolts. 29. The engines shall be securely anchored and held in place with a sufficient number of foundation bolts.

Castings. 30. All castings shall be designed to avoid sudden changes of section, and of such forms as will cool uniformly without shrinkage strains.

31. At all flanges of castings there shall be a reinforcement, or addition of metal, of at least 30 per cent of the regular thickness, which shall extend in length or height at least twice the total thickness of the metal at the reinforcement. All flanges to be of not less thickness than the total metal at the reinforcement.

32. All castings must have good-sized fillets at all corners; no small brackets will be allowed.

Reheaters. 33. Reheaters shall be designed with proper heating area, and constructed to be absolutely steam tight under all working conditions to which they will be subjected, and must have room and facilities for examination, repairs, and renewals.

Jackets and Side Pipes. 34. Steam jackets must be secured to the steam cylinder in such a manner as to allow free and easy expansion and contraction, without causing internal leakage of joints, or derangement of any description to jackets or cylinders, or undue strains in any part; and must be arranged to insure proper circulation of steam and ready removal of the jacket water. Side pipes shall be provided with copper expansion joints.

35. All flat plates and surfaces acted upon by pressure must be substantiatly proportioned and strengthened with heavy ribs, to make them of ample stiffness and strength to safely carry the loads to which they will be subjected.

36. All handholes and manholes shall be of ample size, well fitted, and so constructed as to be readily opened and closed, and where necessary shall be provided with cranes.

37. Priming and draining pipes and valves shall be provided for filling and emptying the pump chamber.

Condenser. 38. The condensers must safely stand all working stresses to which they may be subjected, without leakage or weakness of any description.

Examination and Repairs. 39. The condensers shall be constructed to give ample facilities and room for the examination, insertion, and withdrawal of tubes and packing of joints. The tubes must be provided with perfectly tight and easily removable packings, allowing for expansion and contraction without injury or leakage.

40. The condensers shall be so arranged that the amount of water passing through, or condensing surface, can be adjusted to temperatures of circulating water, varying from 40° to 80° F.

41. Arrangement must be made for proper distribution and circulation of the exhaust steam and condensing water on the cooling surfaces of the condenser, without injurious impingement of the steam or condensing water.

42. All glands, nuts, and washers used in the condensers shall be made of composition; all bolts used inside the condensers shall be made of bronze.

Hot Well. 43. An open hot well shall be provided. The discharge of air pumps into hot well shall be above the water level.

Suction and Discharge Pipes. 44. The suction and discharge pipes shall be thirty-six inches in diameter.

45. For each engine there shall be a single suction or inlet pipe, which shall be attached to the gate valve, furnished by the City of St. Louis, shown in the plans of the pump pits.

46. The discharge pipe for each engine shall be carried up to an elevation of 113.6, and then horizontally through and to a distance of two feet from the outside of the pump pit wall, and shall be provided with a drilled flange for connection to pump main.

Air Chambers. 47. Each engine shall be provided with air vessels of sufficient capacity to insures mooth, easy, and equal action of the pumps.

By-pass. 48. Each engine shall be provided with a by-pass pipe, arranged to facilitate draining the pump mains and starting the engines.

Relief Valves. 49. Each engine shall be provided with pressure relief valves, designed and arranged to by-pass the discharge of its pumps when the pressure on the pump mains exceeds 125 pounds per square inch.

50. The pressure relief to be of sufficient capacity to by-pass total discharge of the engine.

51. There shall be platforms or galleries of cast-iron plates or wrought-iron open work at convenient locations upon the pump and steam ends, which will allow all of the operations necessary in running and maintaining the engines to be safely and easily performed.

52. The Contractor shall design, furnish, and erect iron stairways, landings, and galleries leading from the top gallery down to the bottom of the pump pit, with all intermediate galleries and supporting girders, beams, and composition railings required to make them complete and satisfactory in all respects. All the above to be made of neat and harmonious proportions, and arranged to leave sufficient space for hoisting and removing the pump chambers and other parts of the machinery without disturbing any beams, bedplates, or other stationary parts, or necessitating the removal of stairways, landings, or galleries to any great extent.

Light. 53. The galleries, stairs, and platforms shall be arranged to secure as good diffusion of light in the pump pit as possible.

54. The stairs to be made without risers, and where practicable the tread plates and all gallery plates shall be made of a suitable open-work pattern.

All parts of stairs, galleries, and platforms shall be accessible for inspection and painting.

Mechanism and Wearing Parts.

Strength and Stiffness. 55. All moving parts shall be of ample strength and of sufficient stiffness to prevent undue vibrations in operation.

Wearing Surfaces. 56. All journals and wearing surfaces shall be of sufficient size and of proper proportion to avoid excessive pressure and heating.

Counter-boring. 57. Provision shall be made to prevent the wearing of shoulders on either stationary or moving parts at points of extreme travel.

Journals. 58. All journals above four inches in diameter shall have provisions for horizontal and vertical adjustment.

Bushings. 59. All glands and guide rings of stuffing boxes shall be provided with composition linings forced in and securely held in

place, and the glands shall be cupped out to make proper receptacles for lubricants, leakage water, etc.

Valves, etc. 60. The bodies of all valves, three inches in diameter and smaller, shall be entirely of composition, but the bodies of valves, larger than three inches, may be of cast iron, with composition valve and valve seats.

61. All valves, fittings, fixtures, and appurtenances used shall be of an approved design.

Steam End. 62. The valve motions and starting arrangements of the engines shall be such that each engine can be promptly and safely started and operated by one engineer.

Valves. 63. The steam distribution valves shall be of a known reliable type. They shall be well balanced and so designed as to work with the minimum friction, to wear even and steam tight, and to have proper facilities for refitting and adjusting.

Valve Motion and Regulation. 64. The steam valve mechanism shall be of ample strength and durability; must be reliable in all its functions and free from any danger of failure by derangement or rebounding. The engine shall be provided with an automatic device to prevent racing in case of a broken pump main.

Cut-off. 65. The engines shall be fitted with a variable cut-off mechanism so arranged as to be easily and quickly adjusted while the engines are in operation.

Throttle. 66. The running throttle valves of the engines shall be of a well-balanced type, and operate quickly and easily under full steam pressure.

Pistons. 67. The steam pistons shall be provided with Babbitt and Harris piston packing, or packing which, in the opinion of the Water Commissioner, is equally efficient. Piston rods shall be provided with metallic packing equal to that of the U. S. Metallic Packing Company.

68. Steam valves above six inches in diameter shall have steel stems provided with Phosphor bronze nuts.

Pump End. 69. The area of the suction and discharge valves shall be sufficient to insure proper filling and discharging of the pumps under all conditions, but in no case shall the total suction valve area or the total discharge valve area of each engine be less than 10 square feet.

Valves. 70. The pump valves shall be designed and constructed

to open and close promptly and quietly, shall be tight and of ample strength, and shall be especially designed for facility of repairs and renewals.

71. All stems of water valves shall be made of Muntz metal or Phosphor bronze.

Connecting Pieces. 72. All connecting, piston, plunger, and distance rods, and all movable parts, must be of ample strength and stiffness to withstand working stresses.

Guides. 73. The piston rods, plunger and plunger rods, and all reciprocating parts, shall have properly designed guides and crossheads. The crossheads shall have shoes adjustable for wear.

Boxes. 74. All journals and pins of connecting and valve rods, and of all reciprocating and oscillating rods, shall have well proportioned ends with composition bushes or boxes, and provided, where necessary, for adjustment of wear. Each link or connecting rod shall, at the different ends, have provisions for compensation of wear in the same direction.

75. All strap, solid, or box ends shall be of a shape having great strength and stiffness, holding the composition boxes securely, and giving a neat and workmanlike appearance.

Locked Nuts. 76. All nuts of pillow block cap bolts and follower bolts of pistons, all screw joints of moving parts and all keys, shall be provided with a secure locking device.

Fly-Wheels. 77. Fly-wheel or beam shafts shall rest in pillow blocks very securely and rigidly supported at ample distances apart.

Air Pumps. 78. The design and construction of the air pumps must be such that they will at all times perform their work promptly without noise or injurious shocks.

79. The air pump, boiler feed pump, air chamber supply, and all accessory pumps required to run the engine, shall be driven from the main engine. An independent air compressor shall be provided for loading air chambers.

MATERIALS.

80. All materials used throughout this construction must be of the special class and grade called for in the specifications and designated on the drawings, and shall in each case fully stand the specified tests.

Castings. 81. All castings shall be free from blow holes, flaws,

scabs, and defects of any description, and shall be smooth, close grained, sound, tough, and of true forms and dimensions.

82. All casting must be done in accordance with the best modern foundry practice, to obtain castings of the very best quality. Castings above 500 pounds in weight shall be moulded in dry sand or loam. Great care must be taken to make all castings as nearly as practicable of uniform thickness throughout.

83. No plugging or other stopping of holes or defects of castings will be allowed.

Cast Iron. 84. The cast iron used in the steam cylinders, the steam distribution valves, the barrels of air pumps and the water plungers shall be close, fine grained, hard and uniform in character, and of good wearing qualities. The cast iron used in all other parts of this construction shall be of superior quality, tough, and of even grain, and shall possess a tensile strength of not less than 22,000 pounds per square inch. Test bars of the metal 2 inches by 1 inch, when broken transversely, 24 inches between supports and loaded in the centre, shall have a breaking load of not less than 2,200 pounds, and shall have a total deflection of not less than 0.36 of an inch before breaking.

Test Bars. 85. The test bars shall be cast as nearly as possible to the above dimensions without finishing, but corrections will be made by the Water Commissioner for variations in thickness and width, and the corrected results must conform to the above requirements.

86. If any two test bars, cast the same day, show a tensile strength less than 22,000 pounds per square inch, or do not show the required cross breaking load or deflection, all the castings made from the melt from which the samples were taken may be rejected.

Steel. 87. All steel castings used in the construction shall be thoroughly annealed, and possess a tensile strength of 65,000 to 75,000 pounds, and 15 per cent elongation in two inches.

88. All steel forgings used in this construction shall be equal to forgings manufactured by the Bethlehem Iron Co., Bethlehem, Pa., and have a tensile strength of not less than 75,000 pounds per square inch of section, and show an elongation of 20 per cent in four diameters, specimens to be taken from full-sized forged prolongation, after annealing. Shafts and crank-pins shall be hydraulic forged fluid-compressed steel. All steel forgings shall be thoroughly annealed.

Wrought Iron. 89. All of the wrought iron used shall be tough, fibrous, and uniform in character, and specimens broken in the testing machine shall show a tensile strength of not less than 50,000 pounds per square inch, with an elongation of 18 per cent in eight diameters.

90. If any specimen of steel or wrought iron shall not conform to the above requirements, all material of the lot from which the specimen was taken will be rejected.

Bolts. 91. The Water Commissioner may take at random any wrought-iron bolt and nut, and have it broken in a testing machine. If any two bolts shall not fill the above stipulated requirement, for wrought iron, the whole lot of that size and make may be rejected; the effective area used in computing the breaking strength will be the area corresponding to the smallest diameter at the bottom of the threads, when cut in accordance with the U. S. standard.

Rivets. 92. Rivets shall be made from the best refined iron, and must be capable of being bent cold until the sides are in close contact without sign of fracture on the convex side.

Shapes. 93. All rolled wrought-iron shapes shall be free from twists, bends, seams, blisters, buckles, cinder spots, or imperfect edges. All sheet and plate iron must be capable of being worked at a proper heat without injury.

Rods. 94. All rods shall be formed in one continuous rolled or forged piece without weld.

Composition. 95. All the composition metal used shall consist of the best quality, new material only, of mixtures specially adapted for the work in each case, and approved by the Water Commissioner.

Phosphor Bronze. 96. All Phosphor bronze used must be homogeneous and uniform in character, and shall have a tensile strength of not less than 30,000 pounds per square inch, with an elongation of 15 per cent in eight diameters.

Muntz Metal. 97. All Muntz metal used must be homogeneous and uniform in character, and specimens broken in a testing machine shall show a tensile strength of not less than 50,000 pounds per square inch, and an elongation of 20 per cent in eight diameters.

98. Finished bolts and nuts of Muntz metal or Phosphor bronze may be tested in the same manner as specified for wrought iron, and if any two bolts shall not fulfil the requirements, the whole lot of that size and make will be rejected.

Test Bars. 99. Test specimens and samples of castings, forgings, composition, or any other material used in this construction, shall be prepared ready for testing, and supplied in the number, shape, finish, and sizes required by the Water Commissioner, and shall be prepared as may be directed at any time during the pouring or working of the materials.

For all material taken by the Water Commissioner for testing, the following prices will be paid, which shall include the cost of preparing and finishing the test specimens, viz.:

For all wrought iron or steel, the sum of ten cents per pound.

For all composition, the sum of thirty cents per pound.

For all cast iron, the sum of three cents per pound.

All broken material to belong to the City of St. Louis.

Babbitt Metal. 100. The Babbitt metal used throughout the construction must be of the following approximate proportions by analysis: 88 per cent pure tin, eight per cent antimony, and four per cent Lake Superior copper.

Rubber. 101. All rubber for valves and gaskets must be of a suitable quality, approved by the Water Commissioner before it is used.

Other Materials. 102. All other material used in the engines and not mentioned in these specifications will be subject to inspection, test, and approval by the Water Commissioner before it is used.

CONSTRUCTION.

Workmanship. 103. The workmanship and finish of the pumping engines throughout shall be equal to the best American practice, and in every respect satisfactory to the Water Commissioner.

Machine Worked. 104. All surfaces worked in machine tools must be true and smooth, and accurately conform to the drawings in shape, size, and alignment.

105. The bearing surfaces of all sole and bed plates shall be planed.

106. If fly-wheels are used, the parts shall be fitted and fastened together in the most careful and workmanlike manner, and the outer circumferences and the sides of the rim shall be turned smooth and true.

Joints. 107. All joints of bed plate and frame to be planed or faced, and carefully fitted.

Boring. 108. The steam cylinders shall be bored in a vertical position, perfectly smooth and truly cylindrical, with a boring bar of proper diameter.

Turning. 109. All circular flanges shall be faced on the outer circumference.

110. All centres of lathe work must be made of ample size and carefully preserved.

111. All corners in journals and elsewhere in turned work shall be rounded to proper radii.

Joints. 112. All steam joints shall be made in an approved manner, with a thin gasket of Jenkins' Usidurian packing.

113. All water joints to be made with approved gaskets, arranged with special care to prevent blowing out.

114. All seats of steam and water gates must be scraped and ground tight.

Journals. 115. All journals to be turned straight, cylindrical, and smooth. Particular attention and care shall be given to the proper fitting and scraping of all journal boxes, in order to make the same of an extraordinary good bearing surface and accurate fit.

Straps, etc. 116. Straps, gibs, keys, reamed bolts, bushings, and boxes of all connecting rods must be fitted with the utmost care and accuracy, and finished in a thorough and workmanlike manner.

Scraping. 117. The final fitting marks shall, for all parts, be preserved for examination, and must in all cases be satisfactory to the Water Commissioner.

118. All journal boxes, pins, keys, and other details of the machinery shall be taken apart at any time during the process of fitting or erecting, when the Water Commissioner so directs, to allow a thorough examination of fit and workmanship.

Gear. 119. If gear wheels are used in the valve motion of the engines, they shall be properly designed and accurately cut in gear cutting machines.

Cam Treads, etc. 120. The treads of cams and other parts of the valve motion subject to intermittent or sudden motion and heavy wear shall be of tempered steel or case-hardened iron.

Tempering or Hardening. 121. The tempering or hardening processes must be so conducted that parts will retain their proper size and shapes and have the requisite hardness.

Centring. 122. All parts of the engines must be well secured

and correctly centred with accurately fitted dowel pins, reamed bolts or male and female joints.

Bolting. 123. All flanges must be cast solid, and all bolt holes shall be drilled with perfectly sharpened and centred twist-drills to insure round holes. All flanges shall be spot faced around bolt holes to uniform thickness.

Dowel Pins. 124. All dowel pins must be of proper taper, and well fitted; and where necessary, shall have proper facilities for removal.

Taper. 125. All holes intended to receive tapering parts shall be carefully reemed and ground, and the tapering parts driven or forced into place.

Threads. 126. Nuts and bolt-heads and all threads shall be of the U. S. standard, except where special threads are necessary.

127. The threads and shanks of all bolts above $\frac{5}{8}$-inch in diameter shall be cut and turned in a lathe or special bolt machine, and the ends of all bolts shall be finished with neat spherical ends.

Finished Nuts. 128. Case-hardened, finished, and polished nuts shall be used in all exposed work above the operating floor, and also for all parts requiring frequent removal and adjustment. All other nuts and bolt-heads above the upper floor level, and nuts for all stuffing boxes, and at such other places as may be necessary, shall be finished.

129. Finished Phosphor bronze nuts and rolled Muntz metal studs and bolts to be used for all fastenings inside the pump chambers, and for all glands of stuffing boxes on the pump.

Cold Pressed Nuts. 130. Cold pressed nuts shall be used for all stationary parts of the pump chambers, and in all cases where not otherwise specified.

Hexagonal. 131. All nuts and bolt-heads shall be hexagonal in shape, and must be faced on top and bottom, square to the axis of bolt. The sides shall fit their wrenches accurately.

Keys. 132. All keys must be accurately fitted and properly driven or forced into place, and must be of appropriate size and taper..

133. All riveted work shall be specially designed for its particular uses, and executed in a thorough and workmanlike manner.

Calking. 134. All riveted joints subject to pressure shall be thoroughly and neatly calked with a round-nosed tool.

Finishing. 135. All connecting rods, links, and valve rods shall be draw-file finished.

136. All bright and specially finished work must be of the highest grade and entirely free from scratches, specks, and flaws.

137. All visible composition work shall have a bright finish.

138. All exposed machine-worked surfaces of all parts above the upper floor level, and of all moving parts, except fly-wheels, shall have a bright finish.

Lagging. 139. The steam cylinders, steam chest, reheaters, steam and distribution pipe and other heated surfaces of the machinery, when necessary, shall be protected by neat walnut lagging, securely fastened and held in place by brass bands and button-headed brass screws, and bright finished false covers.

Covering. 140. All steam pipes and heated surfaces shall be protected with Magnesia non-conducting covering at least 1½ inches thick.

141. No non-conductors, lagging or false covers shall be applied until the construction has been thoroughly tested by working steam pressure, and all leakages and defects developed have been thoroughly remedied.

ERECTION.

In Shop. 142. The Contractor shall erect in his shop such parts of the steam and water ends of the engines as may be necessary, in order that the final erection can be carried on with despatch in a thorough and workmanlike manner.

Transporting. 143. The Contractor shall, at his own expense and risk, transport all parts of the machinery to the pumping station, and will be allowed the use, at his own cost and expense for operating, of the 20-ton power travelling crane in the engine house for erecting, but shall so manage the work as not to interfere with engines Nos. 7 and 8 in the adjacent pit.

144. Bed plates and castings, resting on pit bottom, shall be provided with a cement joint of proper thickness, and made satisfactory to the Water Commissioner.

145. All joints between stationary parts must be made with the utmost accuracy and precision, insuring perfect and permanent alignment. None of the parts shall be unduly strained in lining up.

Other Work. 146. The Contractor shall so conduct his opera-

tions as not to interfere with the work of other Contractors, and the disposal of his tools and materials, during storage and erection, will be subject to the approval of the Water Commissioner.

Water. 147. The party of the second part will furnish and set the gate valves in the suction pipes, but the Contractor shall pump out all accumulated water in the pump pit before commencing erection, and do all necessary pumping during erection of engines.

Protection of Parts. 148. All finished parts must be well protected in shops and during transportation, to prevent injury and abrasion.

Damage. 149. All injured parts must be replaced, when, in the judgment of the Water Commissioner, refitting will not suffice.

Cleaning Up. 150. The Contractor shall erect and remove all staging, scaffolding, trestle work for tracks, etc., needed in erecting the engines, and leave the pump pit, engine room and premises neat and clean.

Damage to Masonry, etc. 151. The Contractor shall, at his own cost, make good any damage to masonry, buildings, or other property of the city of St. Louis, occasioned by the Contractor or his employees in the transportation and erection of the machinery.

Storage of Machinery Parts. 152. The city of St. Louis will furnish space within its premises for the reception of the various parts of the machinery, but shall not be responsible for the safekeeping of these parts, nor for damage caused to them from exposure or other cause.

PAINTING.

153. All castings and details must be inspected and approved before painting, and in no case shall paint be applied until all surfaces are trimmed and thoroughly cleaned.

Paraffine Varnish. 154. All unfinished iron work not visible from the engine room floor (except where otherwise required), and that above the floor intended to be encased, shall be thoroughly painted inside and out with three coats of No. 1 Paraffine varnish, applied hot. The first coat shall be put on at the shop, and the others after erection, excepting for inside surfaces of pumps, pipes, etc., which shall receive two coats at the shop and one after erection.

Oil Paint. 155. All unfinished iron work visible from the engine room floor shall be thoroughly cleaned, filled, rubbed down, and painted with four coats of the best quality of paint with strictly pure

156. All parts covered by non-conductors must be thoroughly cleaned, and painted with three coats of Paraffine varnish.

157. All Magnesia covering, not protected by lagging, shall be given three coats of paint.

158. Walnut lagging shall be well filled and given three coats of best varnish thoroughly rubbed down.

159. All paint and varnish shall be of a color and grade approved by the Water Commissioner, and shall be applied and rubbed down to his satisfaction.

Finished Iron Work. 160. All finished and polished surfaces must be kept entirely free from rust until erected and finally accepted.

TESTING.

Pressure. 161. After erection has been completed, a blank flange shall be bolted on the out-door end of the discharge pipe, and the whole construction tested with hydraulic pressure. A force pump shall be connected to the discharge pipe, and a pressure of 200 pounds per square inch applied in such manner as to test the pumps, pump valves, air vessels, discharge pipes, pump rods, and the frames of the engines. After this test the engine is to be run to full capacity, discharging through the pressure relief valves for the purpose of testing same; a further test may be made by suddenly opening gate on pump main to test speed-controlling device mentioned in Section 64.

These tests must be conducted by the Contractor with great care and in a manner satisfactory to the Water Commissioner.

The Contractor shall furnish all labor necessary, and all piping, cocks, valves, gauges, force pumps, flanges, and appliances required in the tests.

Duty Tests. 162. For the purpose of determining the efficiency of the engines furnished under this contract, there shall be a duty test of twenty-four hours continuous run for each engine. These tests shall be conducted by the Water Commissioner.

163. The water of condensation from all steam jackets and reheaters shall be gathered and its weight carefully determined, and it shall be charged against the engines during all of the duty tests.

164. The total weight of water fed to the boilers during the tests shall be considered the amount of steam used when corrected for entrainment.

165. Steam used for running the boiler feed pumps during the duty tests will be charged against the engines.
linseed oil, and two coats of best varnish. The first coat shall be put on at the shop and the others after erection.

Speed. 166. If, in the opinion of the Water Commissioner, the speed of the engines at any time during the twenty-four hours duty test is such as to jeopardize their safety, he shall have the right to order them run at such reduced speed as will give a smooth and quiet action.

Head (h). 167. The head (h) to be inserted into the formula for computing the duty of the engines during the test shall be ascertained by attaching a gauge to the discharge pipe close to where it turns into and runs through the foundation walls of the pit, and by the elevation of the water in the wet well.

168. Any part or detail of the engines showing undue strain or weakness of any description must be replaced, and all defects developed in these tests shall be corrected by the Contractor to the entire satisfaction of the Water Commissioner.

ADDITIONAL APPLIANCES.

Wrenches. 169. The Contractor shall furnish for all sizes of bolts a complete set of wrenches for each engine, accurately fitted to the respective sizes of nuts. The wrenches for all finished nuts about the engines shall have a bright finish and shall be marked with their respective sizes.

170. Each engine shall be provided with one steam gauge graduated from 0 to 250 pounds, one vacuum gauge, one suitable steam gauge on each receiver, and one engine revolution counter; all of them to have brass cases, triple silver plated. The dials of gauges to be twelve (12) inches in diameter.

171. Each air chamber of the main pumps shall be provided with one glass water gauge of satisfactory design. The air pump discharge of each engine shall be provided with a suitable, permanently attached thermometer of appropriate design.

172. Each steam cylinder, main and air pumps of the two engines shall be provided with permanent piping, fixtures, and motion appliances for attaching and working the indicators. All valves, cocks, pipes, and appliances for the attachment of the indicators to the steam

cylinders and pumps shall be made of composition, of ample size, and complete in every respect.

Oil Cups, etc. 173. All journals must be provided with sight-feed oil cups. There shall also be brass drip pans or pockets at all journals and oiling places to catch lubricants.

174. The steam cylinders shall be fitted with sight-feed lubricators.

175. There shall be valves, pipes, and drip pans at all places where necessary, for receiving and conveying water from stuffing boxes, etc.

176. The Contractor shall furnish at his own cost and expense all cylinder and lubricating oil, grease, and packing required to run the engines for the first six months.

REPAIRS.

177. Near the end of the year of probation, the Water Commissioner will make an examination of the engines, and any part or detail found to be defective or injured through excessive wear, overstrain, bad material, or faulty design, shall be replaced by the Contractor, at his own cost and expense, to the satisfaction of the Water Commissioner.

. . . . . .

Q The part of the first part further agree that each engine furnished under this contract shall have a pumping capacity of fifteen million U. S. gallons in twenty-four hours. The capacity to be at a speed that will insure smooth and quiet action, and to be determined by the Water Commissioner.

R The part of the first part hereby agree that the pumping engines furnished under this contract shall perform, during a running test of twenty-four hours, a duty of one hundred and thirty-five million foot-pounds per thousand pounds of dry steam.

The part of the first part further agree that in case either engine fails to perform a duty of one hundred and thirty-five million foot-pounds per thousand pounds of steam, during the duty test of twenty-four hours, ... will pay to the party of the second part, as an agreed measure of damages for lack of efficiency of the engine, in the ratio of $2,000.00 for each one million foot-pounds which the duty falls below one hundred and thirty-five million.

In case either engine exceeds, during the twenty-four hour duty test, an average duty of one hundred and thirty-five millions foot-pounds per thousand pounds of steam, the party of the second part agrees to pay to the part of the first part, as a reward for the superior efficiency of the engine, an amount to be in the ratio of $1,000.00 for each one million foot-pounds which the duty exceeds one hundred and thirty-five million.

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NOTE.

The illustrations which accompany Mr. Wood's paper on "The Future Water Supply of New Bedford," were kindly furnished by Messrs. Rice and Evans, the Engineers of the work, and are from photographs made by Geo. S. Rice, C. E.